

TREE VOLUME TABLES FOR BAEN (*AVICENNIA OFFICINALIS* L.) IN THE COASTAL PLANTATIONS OF BANGLADESH

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INTRODUCTION

Baen (*Avicennia officinalis* L.) is the second important species followed by Keora (*Sonneratia apetala* Buch.-Ham.) for the coastal plantations in Bangladesh. The species is being planted since 1969 at a spacing of 0.9 m X 0.9 m to 1.2 m X 1.2 m. The timber of the species may be used as fuelwood, anchor logs, leaves as fodder, resin from bark as contraceptive etc. The older plantations are now suitable for harvesting and time has come to replace baen with suitable species for subsequent rotations.

The forest department needs to take some decision about its future management policies. To have information about the stocking and probable yield of these plantations, an inventory work therefore was undertaken in 1986. The plantations raised during the period 1969-79 were considered as maturing plantations for the inventory purpose. For estimation of volume, necessary data were collected from 99 trees and the general regression model suitable for

different species in Bangladesh were tried and observed that the model gives a good fit (Drigo *et al*, 1987). But, it was found out later that these equations give excess underbark volumes to a top end diameter in comparison to the total over bark volume after a certain dbh and height limit.

Therefore, additional data were collected to have a well representation of the baen plantations in coastal areas of Bangladesh and an attempt was made to find out the most suitable volume equations for general use.

COLLECTION OF DATA

Baen plantations are available in Chittagong and Noakhali Coastal Afforestation (CA) Divisions. From each Forest Division, 2-4 Forest Ranges with plantations of maximum years were selected and for each plantation year, two plantations were selected at random in each C/A division.

Data were collected from the plantation areas with crown closer more than 30 percent. In each plantation two sample plots, each of these plots with three sub-plots were laid out at random. The sub-plots were with an area of 0.01 hectare each and the total area of a sample plot was 0.03 ha. From each sub-plot, 2-3 representative sample trees were measured for volume estimation. Data were collected from standing trees. Measurements on diameters at breast height (dbh), total height (H), diameters

at one meters interval from one metre above ground level to a top end diameter of 7.0 cm overbark were taken. The bark thicknesses at each points of diameter measurement were also taken to estimate the underbark diameters. There were a few data available for the larger dbh and height classes in the initial measurements. Hence, additional data were collected again in 1991 for larger tree available in the coastal plantations. A total of 308 baen trees were measured (Table 1).

Table 1. Diameter at breast height and total height class distribution of the sample trees

Dbh (cm)	Height in meters									Total
	6	7	8	9	10	11	12	13	14	
10	9	20	15	6	5	-	1	-	-	56
12	1	8	19	11	6	-	-	-	-	45
14	6	8	19	21	16	6	1	-	-	77
16	-	9	10	23	14	8	2	-	-	66
18	1	3	3	9	13	5	3	-	1	38
20	-	-	-	4	4	3	1	1	-	13
22	-	-	-	3	4	1	2	1	-	11
24	-	-	-	-	-	-	1	-	-	1
26	-	-	-	-	-	-	-	-	-	0
28	-	-	-	-	-	-	1	-	-	1
TOTAL	17	48	66	77	62	23	12	2	1	308

COMPILATION OF DATA

The volumes of all the sections except the top and bottom portions were computed by using the mean cross-sectional area of the two ends of each section (smallian formula). The bottom section was assumed cylindrical. The top most section was assumed as a cone and volume was computed as one third of the cylindrical volume of the portion. The top end diameter measurement for each tree was considered as the base diameter of the cone. The volumes of the cone was ignored for estimation of underbark tree volumes. The individual tree volume was then estimated by summing up the volumes of each section of a tree. These individual tree volumes (V) were related to dbh (D) and total height (H) by regression analyses using various functions and transformations as required in the regression models.

COMPUTATION OF VOLUME FUNCTION

Multiple regression analyses were done to select the best suited equations. The following 10 models were tried for best fit with different variables as follows :

1. $V = b_0 + b_1 D$
2. $V = b_0 + b_1 D + b_2 D^2$
3. $V = b_0 + b_1 D^2$
4. $V = b_0 + b_1 D^2 H$
5. $V = b_0 + b_1 D^2 + b_2 H + b_3 D^2 H$

6. $V = b_0 + b_1 D^2 + b_2 DH + b_3 D^2 H$
7. $\log(V) = b_0 + b_1 \log(D)$
8. $\log(V) = b_0 + b_1 \log(D) + b_2 \log(H)$
9. $V/HD^2 = b_0 + b_1 HD^2 + b_2/H + b_3/D^2$
10. $V/HD^2 = b_0 + b_1/D^2 + b_2/H + b_3/D$

Where V, D and H are described as above, b_0 is the regression constant and b_1 , b_2 and b_3 are regression coefficients. The logarithmic functions are to the base e.

These models were run separately for the data of the two CA divisions to select the best suited model for each CA division. These were followed by the examination of the suitability of the selected model for one division applicable for estimation of volumes of the trees of the other division. These were done following all the procedure of validation.

The equation of best fit were chosen based on the highest multiple coefficient of determination, F-ratio, lowest residual mean square and Furnival index. Models were selected for estimation of total volume overbark and total volume underbark to a top end diameter of approximately 7.0 cm overbark. The selected equations were transformed for estimation of volume from girth at breast height (GBH). The equations were also converted for imperial units.

VALIDATION TEST PROCEDURE

The best suited regression equations were tested with a set of independent data of 40 trees collected and compiled in the same procedure. The actual volume of these trees were collectively compared with the corresponding volume predicted by the selected models. The independent tests for validation criteria were the paired t-test (Dawkins, 1975), regression analysis (Cox 1984), Percent absolute deviation.

RESULTS AND DISCUSSIONS

The results of the test criteria revealed that there were no statistically significant

difference among the observed and the estimated volumes for baen trees growing in the plantations of Noakhali and Chittagong Forest Divisions. Therefore, data were pooled together and a set of equations were derived for these two divisions. The mean sum of error squares, multiple coefficient of determination, F-ratio and Furnival index for the selected equations are given in table 2.

The equations for total volume over bark and total volume under bark to a top end diameter of 7.0 cm over bark were selected after the validation of the selected models. The results of the validation test are given in table 3.

Table 2. The mean of error squares, coefficient of determination, F-ratios and Furnival index of the selected equations for estimation of volume of baen in the coastal plantations of Bangladesh

Selected models	MSE	R ²	F	F. I.
V _{mo1} = b ₀ + b ₁ *D ²	0.00039	0.790	1031.47	0.0197
V _{mu1} = b ₀ + b ₁ *D ²	0.00038	0.760	869.98	0.0196
V _{mo2} = b ₀ + b ₁ *D ² *H	0.00026	0.859	1672.16	0.0161
V _{mu2} = b ₀ + b ₁ *D ² *H	0.00026	0.835	1394.75	0.0162

Where :

- o = total volume overbark
- u = underbark volume upto the top end dbh of 7.0 cm
- m = metric units
- 1 = one way volume table
- 2 = two way volume table

Table 3. The results of the validation test of the selected equations

Selected models	A-E = b0 + b1E			A-E = b0 + b1E + b2E ²				
	t	%AD	F	t	F	t	t	Slope
$V_{mo1} = b_0 + b_1 \cdot D^2$	0.208	1.1	0.4157	0.329	5.38	0.40	2.18	44.0
$V_{mu1} = b_0 + b_1 \cdot D^2$	0.300	2.0	0.3934	0.334	4.05	0.42	2.61	43.7
$V_{mo2} = b_0 + b_1 \cdot D^2 \cdot H$	0.377	1.6	0.0295	0.320	0.62	0.29	2.08	44.9
$V_{mu2} = b_0 + b_1 \cdot D^2 \cdot H$	0.496	2.5	0.2755	0.018	0.85	0.51	4.08	43.6

The best selected and transformed/converted volume equations for baen in the Coastal Afforestation Divisions are given below :

$$V_{mu2} = -0.0012 + 0.0000257958 \cdot D^2 H$$

$$V_{mu2} = -0.0012 + 0.00000261 \cdot G^2 H$$

METRIC UNITS

Total volume overbark for one way :

$$V_{mo1} = -0.0049 + 0.00035 \cdot D^2$$

$$V_{mo1} = -0.0049 + 0.0000355 \cdot G^2$$

Total volume underbark to a top end diameter of approximately 7.0 cm overbark :

$$V_{mu1} = -0.0088 + 0.000321 \cdot D^2$$

$$V_{mu1} = -0.0088 + 0.0000325 \cdot G^2$$

Total volume overbark for two way :

$$V_{mo2} = 0.0089 + 0.0000264 \cdot D^2 H$$

$$V_{mo2} = 0.0089 + 0.00000267 \cdot G^2 H$$

Total volume underbark to a top end diameter of approximately 7.0 cm overbark :

IMPERIAL UNITS

Total volume overbark for one way :

$$V_{io1} = -0.176 + 0.08005 \cdot D^2$$

$$V_{io1} = -0.176 + 0.00811 \cdot G^2$$

Total volume underbark to a top end diameter of approximately 3.0 inches overbark :

$$V_{iu1} = -0.312 + 0.07313 \cdot D^2$$

$$V_{iu1} = -0.312 + 0.00741 \cdot G^2$$

Total volume overbark for two way :

$$V_{io2} = 0.315 + 0.001972 \cdot D^2 H$$

$$V_{io2} = 0.315 + 0.0001998 \cdot G^2 H$$

Total volume underbark to a top end diameter of approximately 3.0 inches :

$$V_{iu2} = -0.0044 + 0.00179 \cdot D^2 H$$

$$V_{iu2} = -0.0044 + 0.0001814 \cdot G^2 H$$

where,

- m = metric units
- i = imperial units
- u = underbark volume
- o = overbark total volume
- D = Dbh
- G = Girth at breast height
- H = total height
- 1 = one way volume table
- 2 = two way volume table

Validation of the Selected Models :

The selected models satisfied all the criteria. The slopes were nearly 45 degree and percent total deviations were less than 5%. This nature was considered sufficient to mark the importance of little discrepancies in the horizontal bands of deviations. From the results of the validation of the models, it can be concluded that the selected models can safely be used for estimation of the volumes of the baen tree in the coastal plantations of Bangladesh. After the validation test, volume tables were prepared for ready use and are presented in Appendices I to VI.

CONFIDENCE LIMIT

The volume tables should not be used to determined volumes of individual trees in a stand. These tables may be used for the mean tree of a stand which may be multiplied by the number of stem to get the total volume of the stand. Estimation of volumes for trees much out side the height and dbh ranges shown in the stand table should only be done with caution.

REFERENCES

- Cox, F. 1984. Volume functions for plantations species and elements for growth. Document No. 2. FAO, Rome p2-5, p18, p24, p53 and p56
- Dawkins, H. C. 1975. Statforms. Department of Forestry, University of Oxford. 5 pp
- Drigo, R.; Latif, M. A.; Chowdhury, J. A. and Shaheduzzaman. 1987. The maturing mangrove plantations of the coastal aforestation project. Field document no. 2. FAO/UNDP project BGD/85/085. Assistance to the Forestry Sector-Phase II

Appendix I. Baen (*Avicennia officinalis* L.) in the coastal plantations of Bangladesh, Total volume overbark for dbh and gbh in centimeters and inches

Dbh (cm)	Gbh (cm)	Volume (cu. m)	Dbh (inch)	Gbh (inch)	Volume (cu. ft)
6	19	0.008	2	6	0.14
8	25	0.018	3	9	0.54
10	31	0.030	4	13	1.10
12	38	0.046	5	16	1.83
14	44	0.064	6	19	2.71
16	50	0.085	7	22	3.75
18	57	0.109	8	25	4.95
20	63	0.135	9	28	6.31
22	69	0.165	10	31	7.83
24	75	0.197	11	35	9.51
26	82	0.232	12	38	11.35
28	88	0.270	13	41	13.35
30	94	0.310	14	44	15.51
32	101	0.354	15	47	17.84
34	107	0.400	16	50	20.32
36	113	0.449	17	53	22.96
38	119	0.501	18	57	25.76
40	126	0.555	19	60	28.72
42	132	0.613	20	63	31.85
44	138	0.673	21	66	35.13
46	145	0.736	22	69	38.57
48	151	0.802	23	72	42.17
50	157	0.873	24	75	45.93

Appendix II. Baen (*Avicennia officinalis* L.) in the coastal plantations of Bangladesh, Total volume underbark to top end diameter of 7.0 cm/3.0 inches for dbh and gbh in centimeters and inches

Dbh (cm)	Gbh (cm)	Volume (m ³)	Dbh (in)	Gbh (in)	Volume (ft ³)
8	25	0.012	3	9	0.35
10	31	0.023	4	13	0.86
12	38	0.037	5	16	1.52
14	44	0.054	6	19	2.32
16	50	0.073	7	22	3.27
18	57	0.095	8	25	4.37
20	63	0.120	9	28	5.61
22	69	0.147	10	31	7.00
24	75	0.176	11	35	8.54
26	82	0.208	12	38	10.22
28	88	0.243	13	41	12.05
30	94	0.280	14	44	14.02
32	101	0.320	15	47	16.14
34	107	0.362	16	50	18.41
36	113	0.407	17	53	20.82
38	119	0.455	18	57	23.38
40	126	0.505	19	60	26.09
42	132	0.557	20	63	28.94
44	138	0.613			
46	145	0.670			
48	151	0.731			
50	157	0.794			

Appendix III. Baen (*Avicennia officinalis*) in the coastal plantations of Bangladesh, Total volume overbark in cubic meters for dbh and gbh in centimeters and height in meters

DBH (cm)	GBH (cm)	Height in meters								
		4	6	8	10	12	14	16	18	20
6	19	0.013	0.015	0.017	0.018	0.020	0.022	0.024	0.026	0.028
8	25	0.016	0.019	0.022	0.026	0.029	0.033	0.036	0.039	0.043
10	31	0.019	0.025	0.030	0.035	0.041	0.046	0.051	0.056	0.062
12	38	0.024	0.032	0.039	0.047	0.055	0.062	0.070	0.077	0.085
14	44	0.030	0.040	0.050	0.061	0.071	0.081	0.092	0.102	0.112
16	50	0.036	0.049	0.063	0.076	0.090	0.104	0.117	0.131	0.144
18	57	0.043	0.060	0.077	0.094	0.112	0.129	0.146	0.163	0.180
20	63	0.051	0.072	0.093	0.115	0.136	0.157	0.178	0.199	0.220
22	69	0.060	0.086	0.111	0.137	0.162	0.188	0.213	0.239	0.264
24	75	0.070	0.100	0.131	0.161	0.191	0.222	0.252	0.283	0.313
26	82	0.080	0.116	0.152	0.187	0.223	0.259	0.294	0.330	0.366
28	88	0.092	0.133	0.174	0.216	0.257	0.299	0.340	0.381	0.423
30	94	0.104	0.151	0.199	0.247	0.294	0.342	0.389	0.437	0.484
32	101	0.117	0.171	0.225	0.279	0.333	0.387	0.441	0.496	0.550
34	107	0.131	0.192	0.253	0.314	0.375	0.436	0.497	0.558	0.619
36	113	0.146	0.214	0.283	0.351	0.419	0.488	0.556	0.625	0.693
38	119	0.161	0.238	0.314	0.390	0.466	0.543	0.619	0.695	0.771
40	126	0.178	0.262	0.347	0.431	0.516	0.600	0.685	0.769	0.854
42	132	0.195	0.288	0.381	0.475	0.568	0.661	0.754	0.847	0.940
44	138	0.213	0.316	0.418	0.520	0.622	0.724	0.827	0.929	1.031
46	145	0.232	0.344	0.456	0.568	0.679	0.791	0.903	1.014	1.126
48	151	0.252	0.374	0.496	0.617	0.739	0.860	0.982	1.104	1.225
50	157	0.273	0.405	0.537	0.669	0.801	0.933	1.065	1.197	1.329

Appendix IV. Baen (*Avicennia officinalis*) in the coastal plantations of Bangladesh, Total volume underbark in cubic meters to top end diameter of 7.0 cm overbark for dbh and gbh in centimeters and height in meters

DBH (cm)	GBH (cm)	Height in meters								
		4	6	8	10	12	14	16	18	20
6	19	0.003	0.004	0.006	0.008	0.010	0.012	0.014	0.016	0.017
8	25	0.005	0.009	0.012	0.015	0.019	0.022	0.025	0.029	0.032
10	31	0.009	0.014	0.019	0.025	0.030	0.035	0.040	0.045	0.050
12	38	0.014	0.021	0.029	0.036	0.043	0.051	0.058	0.066	0.073
14	44	0.019	0.029	0.039	0.049	0.059	0.070	0.080	0.090	0.100
16	50	0.025	0.038	0.052	0.065	0.078	0.091	0.104	0.118	0.131
18	57	0.032	0.049	0.066	0.082	0.099	0.116	0.133	0.149	0.166
20	63	0.040	0.061	0.081	0.102	0.123	0.143	0.164	0.185	0.205
22	69	0.049	0.074	0.099	0.124	0.149	0.174	0.199	0.224	0.249
24	75	0.058	0.088	0.118	0.147	0.177	0.207	0.237	0.266	0.296
26	82	0.069	0.103	0.138	0.173	0.208	0.243	0.278	0.313	0.348
28	88	0.080	0.120	0.161	0.201	0.241	0.282	0.322	0.363	0.403
30	94	0.092	0.138	0.185	0.231	0.277	0.324	0.370	0.417	0.463
32	101	0.104	0.157	0.210	0.263	0.316	0.369	0.421	0.474	0.527
34	107	0.118	0.178	0.237	0.297	0.357	0.416	0.476	0.536	0.595
36	113	0.133	0.199	0.266	0.333	0.400	0.467	0.534	0.601	0.667
38	119	0.148	0.222	0.297	0.371	0.446	0.520	0.595	0.669	0.744
40	126	0.164	0.246	0.329	0.412	0.494	0.577	0.659	0.742	0.824
42	132	0.181	0.272	0.363	0.454	0.545	0.636	0.727	0.818	0.909
44	138	0.199	0.298	0.398	0.498	0.598	0.698	0.798	0.898	0.998
46	145	0.217	0.326	0.435	0.545	0.654	0.763	0.872	0.981	1.090
48	151	0.237	0.355	0.474	0.593	0.712	0.831	0.950	1.069	1.187
50	157	0.257	0.386	0.515	0.644	0.773	0.902	1.031	1.160	1.289

Appendix V. Baen (*Avicennia officinalis*) in the coastal plantations of Bangladesh, Total volume overbark in cubic feet for dbh and gbh in inches and height in feet

DBH (in)	GBH (in)	Height in feet								
		10	15	20	25	30	35	40	45	50
2	6	0.39	0.43	0.47	0.51	0.55	0.59	0.63	0.67	0.71
3	9	0.49	0.58	0.67	0.76	0.85	0.94	1.02	1.11	1.20
4	13	0.63	0.79	0.95	1.10	1.26	1.42	1.58	1.73	1.89
5	16	0.81	1.05	1.30	1.55	1.79	2.04	2.29	2.53	2.78
6	19	1.02	1.38	1.73	2.09	2.44	2.80	3.15	3.51	3.86
7	22	1.28	1.76	2.25	2.73	3.21	3.70	4.18	4.66	5.15
8	25	1.58	2.21	2.84	3.47	4.10	4.73	5.36	5.99	6.63
9	28	1.91	2.71	3.51	4.31	5.11	5.91	6.70	7.50	8.30
10	31	2.29	3.27	4.26	5.24	6.23	7.22	8.20	9.19	10.17
11	35	2.70	3.89	5.09	6.28	7.47	8.67	9.86	11.05	12.25
12	38	3.15	4.57	5.99	7.41	8.83	10.25	11.67	13.09	14.51
13	41	3.65	5.31	6.98	8.65	10.31	11.98	13.65	15.31	16.98
14	44	4.18	6.11	8.05	9.98	11.91	13.84	15.78	17.71	19.64
15	47	4.75	6.97	9.19	11.41	13.63	15.84	18.06	20.28	22.50
16	50	5.36	7.89	10.41	12.94	15.46	17.98	20.51	23.03	25.56
17	53	6.01	8.86	11.71	14.56	17.41	20.26	23.11	25.96	28.81
18	57	6.70	9.90	13.09	16.29	19.48	22.68	25.87	29.07	32.26
19	60	7.43	10.99	14.55	18.11	21.67	25.23	28.79	32.35	35.91
20	63	8.20	12.15	16.09	20.03	23.98	27.92	31.87	35.81	39.75

Appendix VI. Baen (*Avicennia officinalis*) in the coastal plantations of Bangladesh, Total volume underbark to top end diameter of 3.0 inches in cubic feet for dbh and gbh inches and height in feet

DBH GBH		Height in feet								
(in)	(in)	10	15	20	25	30	35	40	45	50
2	6	0.07	0.10	0.14	0.17	0.21	0.25	0.28	0.32	0.35
3	9	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80
4	13	0.28	0.43	0.57	0.71	0.85	1.00	1.14	1.28	1.43
5	16	0.44	0.67	0.89	1.11	1.34	1.56	1.79	2.01	2.23
6	19	0.64	0.96	1.28	1.61	1.93	2.25	2.57	2.90	3.22
7	22	0.87	1.31	1.75	2.19	2.63	3.07	3.50	3.94	4.38
8	25	1.14	1.71	2.29	2.86	3.43	4.01	4.58	5.15	5.72
9	28	1.45	2.17	2.90	3.62	4.35	5.07	5.80	6.52	7.25
10	31	1.79	2.68	3.58	4.47	5.37	6.26	7.16	8.05	8.95
11	35	2.16	3.24	4.33	5.41	6.49	7.58	8.66	9.74	10.83
12	38	2.57	3.86	5.15	6.44	7.73	9.02	10.31	11.59	12.88
13	41	3.02	4.53	6.05	7.56	9.07	10.58	12.10	13.61	15.12
14	44	3.50	5.26	7.01	8.77	10.52	12.28	14.03	15.78	17.54
15	47	4.02	6.04	8.05	10.06	12.08	14.09	16.11	18.12	20.13
16	50	4.58	6.87	9.16	11.45	13.74	16.03	18.33	20.62	22.91
17	53	5.17	7.76	10.34	12.93	15.51	18.10	20.69	23.27	25.86
18	57	5.80	8.70	11.59	14.49	17.39	20.29	23.19	26.09	28.99
19	60	6.46	9.69	12.92	16.15	19.38	22.61	25.84	29.07	32.31
20	63	7.16	10.74	14.32	17.90	21.48	25.06	28.64	32.22	35.80