

## TREE VOLUME TABLES FOR KEORA (*SONNERATIA APETALA* BUCH.-HAM) IN THE COASTAL PLANTATIONS OF BANGLADESH

M. F. Rahman, S. Das, N. A. Reza, J. A. Chowdhury and M. A. Latif

### INTRODUCTION

Keora (*Sonneratia apetala* Buch.-Ham) is the principal species for the coastal plantations in Bangladesh. The species is being planted since 1967 at a spacing of 1.2 m x 1.2 m to 1.8 m x 1.8 m. The timber of the species may be used as packing boxes, bobbins, joinery, doors, windows, pulp wood, hard board, etc. The older plantations are now suitable for harvesting and time has come to replace keora 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 and included for the inventory purpose. For estimation of volumes, necessary data were collected 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 later found out that these equations give excess underbark volumes in comparison to the total over-bark volume after a certain dbh and height limit. Therefore, the necessity of reliable volume tables were felt and an attempt was made to prepare the present volume tables.

### COLLECTION OF DATA

The study was conducted in the four Coastal Afforestation (CA) Divisions, namely, Chittagong, Noakhali, Bhola and

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

DBH	HEIGHT IN METERS										Total
	6	8	10	12	14	16	18	20	22		
<b>NOAKHALI, BHOLA AND PATUAKHALI</b>											
9	7	29	12	-	-	-	-	-	-	48	
11	3	48	52	17	4	1	-	-	-	125	
13	2	17	51	38	12	4	-	-	-	124	
15	1	4	23	48	28	8	-	-	-	112	
17	-	3	11	28	21	8	1	-	-	72	
19		4	11	21	27	11	3	-	-	77	
21		3	1	12	8	9	5	-	-	38	
23		-	2	5	9	7	2	1	-	26	
25		-	-	3	9	13	4	-	-	29	
27		-	-	1	5	7	6	3	-	22	
29		1	-	-	1	7	2	1	-	12	
31		-	-	-	3	4	1	-	-	8	
33		-	-	-	5	4	3	-	-	12	
35		-	-	1	-	1	-	-	-	2	
37		-	-	-	1	2	1	-	-	4	
43		-	-	-	-	1	-	1	-	2	
<b>TOTAL</b>	<b>13</b>	<b>101</b>	<b>157</b>	<b>145</b>	<b>108</b>	<b>89</b>	<b>67</b>	<b>27</b>	<b>6</b>	<b>713</b>	
<b>CHITTAGONG</b>											
10	22	29	9	2	-	-	-	-	-	62	
12	4	19	25	7	-	-	-	-	-	55	
14	1	18	13	10	2	-	-	-	-	44	
16	1	13	17	9	1	-	-	-	-	41	
18	-	3	10	21	8	2	2	-	-	46	
20	-	2	10	16	9	5	1	-	-	43	
22	-	1	3	20	9	6	5	-	-	44	
24	-	-	-	4	5	1	1	-	-	11	
26	-	-	1	2	4	2	-	-	-	9	
28	-	-	1	3	-	1	-	-	-	5	
30	-	-	-	1	1	-	-	-	-	2	
<b>TOTAL</b>	<b>28</b>	<b>85</b>	<b>89</b>	<b>95</b>	<b>39</b>	<b>17</b>	<b>9</b>	-	-	<b>362</b>	

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 four CA divisions to select the best suited model for each of the 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 divisions. These were done following all the procedure of validation.

The equations of best fit were chosen based in the highest multiple coefficient of determination and F-ratio and lowest residual mean square. 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 on 80 trees for the three divisions and 40 trees for Chittagong collected and compiled in the same procedure. The actual volumes 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) and Percent absolute deviation (% AD).

#### 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 keora trees growing in the plantations of each of Patuakhali, Bhola and Noakhali. But the observed and estimated volumes for Chittagong CA division showed significant difference from the corresponding values for other three divisions. Therefore, data of Patuakhali, Barisal and Noakhali were pooled together and a set of equations were derived for these three divisions and a separate set of equations were derived for the data of Chittagong CA division. The sum of squares, multiple coefficient of determination and F-ratio for the selected equations are given in table 2.

The equations for total volume over bark and total volume underbark to a top end diameter of 7.0 cm overbark were selected after the validation of the selected models. The mean sum of squares (MSE), percent absolute deviation (%AD), t-value, slope made by the actual volumes with estimated volumes are given in table 3.

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

Source	df	Equations			
		V <sub>tm1</sub>	V <sub>tm2</sub>	V <sub>um1</sub>	V <sub>um2</sub>
<b>NOAKHALI, BHOLA AND PATUAKHALI CA DIVISION</b>					
Regression SS	1	15.169	15.62	11.758	12.08
Residual SS	711	1.368	0.92	1.35	0.81
R <sup>2</sup>		0.927	0.944	0.912	0.937
F-ratio		7882.144	12067.48	7369.113	10594.14
<b>CHITTAGONG CA DIVISION</b>					
Regression SS	1	2.693	2.998	2.425	2.746
Residual SS	360	0.464	0.160	0.564	0.244
R <sup>2</sup>		0.853	0.949	0.811	0.918
F-ratio		2087.356	6751.916	1719.168	4503.924

Where :

- t = 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 mean sum of error squares, absolute percent variation, t-value and slope of the validation test statistics**

Equation	MSE	% AD	t-ratio	Slope
<b>NOAKHALI, BHOLA and PATUAKHALI CA DIVISION</b>				
V <sub>ntm1</sub>	0.00585	2.5	0.436	44.0
V <sub>ntm2</sub>	0.00195	1.1	0.344	43.2
V <sub>num1</sub>	0.00307	2.7	0.549	44.9
V <sub>num2</sub>	0.00151	1.2	0.340	43.1
<b>CHITTAGONG CA DIVISION</b>				
V <sub>ctm1</sub>	0.000168	4.6	1.54	42.6
V <sub>ctm2</sub>	0.00131	3.5	1.00	42.4
V <sub>cum1</sub>	0.00172	4.8	1.53	41.7
V <sub>cum2</sub>	0.0061	2.9	0.96	42.9

The best selected and transformed/converted volume equations for keora in the Noakhali and Bhola and Patuakhali Coastal Afforestation Divisions are given below :

## METRIC UNITS

Total volume over bark for one way :

$$V_{ntm1} = -0.0306 + 0.000558967 * D^2$$

$$V_{ntm1} = -0.0306 + 0.00005664 * G^2$$

Total volume under bark to a top end diameter of approximately 7.0 cm over bark :

$$V_{num1} = -0.0332 + 0.0004922 * D^2$$

$$V_{num1} = -0.0332 + 0.00004986 * G^2$$

Total volume over bark for two way :

$$V_{ntm2} = 0.0117 + 0.0000280056 * D^2 * H$$

$$V_{ntm2} = 0.0117 + 0.00000283756 * G^2 * H$$

Total volume under bark to a top end diameter of approximately 7.0 cm over bark :

$$V_{num2} = 0.0041 + 0.0000246325 * D^2 * H$$

$$V_{num2} = 0.0041 + 0.00000249579 * G^2 * H$$

## IMPERIAL UNITS

Total volume over bark for one way :

$$V_{nti1} = -1.0086 + 0.12735 * D^2$$

$$V_{nti1} = 1.0086 + 0.0129 * G^2$$

Total volume under bark to a top end diameter of approximately 3.0 inches over bark :

$$V_{nui1} = -1.1724 + 0.1121 * D^2$$

$$V_{nui1} = -1.1724 + 0.01136 * G^2$$

Total Volume over bark for two way :

$$V_{nti2} = 0.4132 + 0.001946 * D^2 * H$$

$$V_{nti2} = 0.4132 + 0.000198 * G^2 * H$$

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

$$V_{nui2} = 0.1448 + 0.00172 * D^2$$

$$V_{nui2} = 0.1448 + 0.000173 * G^2$$

The best selected models along with transformed/converted volume equations for keora in the Chittagong Coastal Afforestation Division are given below :

## METRIC UNITS

Total volume over bark for one way :

$$V_{ctm1} = -0.02288 + 0.0004998 * D^2$$

$$V_{ctm1} = -0.02288 + 0.0000506 * G^2$$

Total volume under bark to a top end diameter of approximately 7.0 cm over bark :

$$V_{cum1} = -0.0256 + 0.0004355 * D^2$$

$$V_{cum1} = -0.0256 + 0.0000441 * G^2$$

Total volume over bark for two way :

$$V_{ctm2} = 0.0073 + 0.00003324 * D^2 * H$$

$$V_{ctm2} = 0.0073 + 0.000003368 * G^2 * H$$

Total volume under bark to a top end diameter of approximately 7.0 cm over bark :

$$V_{cum2} = -0.00088 + 0.0000297 * D^2 * H$$

$$V_{cum2} = -0.00088 + 0.0000030128 * G^2 * H$$

## IMPERIAL UNITS

Total volume over bark for one way :

$$V_{cti1} = -0.789 + 0.115 * D^2$$

$$V_{cti1} = -0.789 + 0.01165 * G^2$$

Total volume under bark to a top end diameter of approximately 3.0 inches over bark :

$$V_{cui1} = -0.9261 + 0.102 * D^2$$

$$V_{cui1} = -0.9261 + 0.01034 * G^2$$

Total volume over bark two way :

$$V_{cti2} = 0.25796 + 0.0023084 * D^2 * H$$

$$V_{cti2} = 0.25796 + 0.0002339 * G^2 * H$$

Total volume under bark to a top end diameter of 3.0 inches under bark for two way :

$$V_{cui2} = -0.03122 + 0.002065 * D^2 * H$$

$$V_{cui2} = -0.03122 + 0.000209 * G^2 * H$$

where, n = Noakhali, Bhola and Patuakhali

c = Chittagong

m = metric units

i = imperial units

u = under bark volume

t = over bark 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 most vivid ones are the slopes and percent total deviations. They are nearly 45 degree and less than 5% respectively. 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 keora trees in the coastal plantations of Bangladesh. After the validation test, volume tables were prepared for ready use and are presented in Appendices I to XII.

## CONFIDENCE LIMIT

These 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 outside the height and dbh ranges shown in the stand table should only be done with caution.

## REFERENCES

- Cox, F. 1984. Volume functions for plantation 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 and Shaheduzzaman, M. 1987. The maturing mangrove plantation of the coastal plantation Project. Field document no. 2. FAO/UNDP project BGD/85/085. 69 pp

**Appendix I. Keora (*Sonneratia apetala* Buch.-Ham.) in the plantations of Noakhali, Bhola and Patuakhali Coastal areas, Total volume overbark and total volume underbark to a top end diameter of 7.0 cm overbark in cubic meters for dbh/gbh in centimeters.**

DBH (cm)	Vntm1 (m <sup>3</sup> )	Vnum1 (m <sup>3</sup> )	GBH (cm)	Vntm1 (m <sup>3</sup> )	Vnum1 (m <sup>3</sup> )
8	0.005		25	0.005	
10	0.025	0.016	30	0.020	0.012
12	0.050	0.038	35	0.039	0.028
14	0.079	0.063	40	0.060	0.047
16	0.112	0.093	45	0.084	0.068
18	0.151	0.126	50	0.111	0.091
20	0.193	0.164	55	0.141	0.118
22	0.240	0.205	60	0.173	0.146
24	0.291	0.250	65	0.209	0.177
26	0.347	0.300	70	0.247	0.211
28	0.408	0.353	75	0.288	0.247
30	0.472	0.410	80	0.332	0.286
32	0.542	0.471	85	0.378	0.327
34	0.616	0.536	90	0.428	0.371
36	0.694	0.605	95	0.480	0.417
38	0.777	0.678	100	0.535	0.465
40	0.864	0.754	105	0.593	0.517
42	0.955	0.835	110	0.654	0.570
44	1.052	0.920	115	0.718	0.626
46	1.152	1.008	120	0.784	0.685
48	1.257	1.101	125	0.854	0.746
50	1.367	1.197	130	0.926	0.809
52	1.481	1.298	135	1.001	0.875
54	1.599	1.402	140	1.079	0.944
56	1.722	1.510	145	1.159	1.015
58	1.850	1.623	150	1.243	1.089
60	1.982	1.739	155	1.329	1.165
			160	1.418	1.243
			165	1.510	1.324
			170	1.605	1.408
			175	1.703	1.494
			180	1.803	1.582
			185	1.907	1.673
			190	2.013	1.767

**Appendix II. Keora (*Sonneratia apetala* Buch. - Ham.) in the plantations of Noakhali, Bhola and Patuakhali Coastal areas, Total volume overbark in cubic meters for dbh/gbh in centimeters and height in meters.**

DBH (cm)	GBH (cm)	Height in meters							
		4	7	10	13	16	19	22	25
8	25	0.019	0.025	0.030	0.035	0.041	0.046	0.052	0.057
10	31	0.023	0.032	0.040	0.049	0.057	0.065	0.074	0.082
12	38	0.028	0.040	0.052	0.065	0.077	0.089	0.101	0.113
14	44	0.034	0.051	0.067	0.084	0.100	0.117	0.133	0.150
16	50	0.041	0.062	0.084	0.106	0.127	0.149	0.170	0.192
18	57	0.048	0.076	0.103	0.130	0.158	0.185	0.212	0.240
20	63	0.057	0.091	0.124	0.158	0.192	0.226	0.259	0.293
22	69	0.066	0.107	0.148	0.189	0.230	0.270	0.311	0.352
24	75	0.077	0.125	0.174	0.222	0.271	0.320	0.368	0.417
26	82	0.088	0.145	0.202	0.259	0.316	0.373	0.430	0.487
28	88	0.100	0.166	0.232	0.298	0.364	0.431	0.497	0.563
30	94	0.113	0.189	0.265	0.341	0.417	0.493	0.568	0.644
32	101	0.127	0.213	0.300	0.386	0.472	0.559	0.645	0.731
34	107	0.142	0.239	0.337	0.434	0.532	0.629	0.727	0.824
36	113	0.158	0.267	0.376	0.485	0.595	0.704	0.813	0.922
38	119	0.174	0.296	0.418	0.539	0.661	0.783	0.905	1.026
40	126	0.192	0.327	0.462	0.596	0.731	0.866	1.001	1.136
42	132	0.210	0.359	0.508	0.656	0.805	0.954	1.103	1.251
44	138	0.230	0.393	0.556	0.719	0.882	1.046	1.209	1.372
46	145	0.250	0.428	0.607	0.785	0.963	1.142	1.320	1.498
48	151	0.271	0.465	0.659	0.854	1.048	1.242	1.436	1.631
50	157	0.293	0.504	0.714	0.925	1.136	1.347	1.558	1.768

**Appendix III. Keora (*Sonneratia apetala* Buch. - Ham.) in the plantations of Noakhali, Bhola and Patuakhali Coastal areas, Total underbark volume to a top end diameter of 7.0 overbark in cubic meters for dbh/gbh in centimeters and height in meters**

DBH (cm)	GBH (cm)	Height in meters							
		4	7	10	13	16	19	22	25
8	25	0.010	0.015	0.020	0.025	0.029	0.034	0.039	0.043
10	31	0.014	0.021	0.029	0.036	0.043	0.051	0.058	0.066
12	38	0.018	0.029	0.039	0.050	0.061	0.071	0.082	0.093
14	44	0.023	0.038	0.052	0.067	0.081	0.096	0.110	0.125
16	50	0.029	0.048	0.067	0.086	0.105	0.124	0.143	0.162
18	57	0.036	0.060	0.084	0.108	0.132	0.156	0.180	0.204
20	63	0.043	0.073	0.103	0.132	0.162	0.191	0.221	0.250
22	69	0.052	0.087	0.123	0.159	0.195	0.231	0.266	0.302
24	75	0.061	0.103	0.146	0.189	0.231	0.274	0.316	0.359
26	82	0.071	0.121	0.171	0.221	0.271	0.320	0.370	0.420
28	88	0.081	0.139	0.197	0.255	0.313	0.371	0.429	0.487
30	94	0.093	0.159	0.226	0.292	0.359	0.425	0.492	0.558
32	101	0.105	0.181	0.256	0.332	0.408	0.483	0.559	0.635
34	107	0.118	0.203	0.289	0.374	0.460	0.545	0.631	0.716
36	113	0.132	0.228	0.323	0.419	0.515	0.611	0.707	0.802
38	119	0.146	0.253	0.360	0.467	0.573	0.680	0.787	0.894
40	126	0.162	0.280	0.398	0.517	0.635	0.753	0.871	0.990
42	132	0.178	0.308	0.439	0.569	0.699	0.830	0.960	1.091
44	138	0.195	0.338	0.481	0.624	0.767	0.910	1.053	1.197
46	145	0.213	0.369	0.525	0.682	0.838	0.995	1.151	1.307
48	151	0.231	0.401	0.572	0.742	0.912	1.083	1.253	1.423
50	157	0.250	0.435	0.620	0.805	0.990	1.174	1.359	1.544

**Appendix IV. Keora (*Sonneratia apetala* Buch. - Ham.) in the plantations of Noakhali, Bhola and Patuakhali Coastal areas, Total volume overbark in cubic feet for dbh/gbh in inches**

DBH (in)	V <sub>nti1</sub> (ft <sup>3</sup> )	V <sub>nui1</sub> (ft <sup>3</sup> )	GBH (in)	V <sub>nti1</sub> (ft <sup>3</sup> )	V <sub>nui1</sub> (ft <sup>3</sup> )
3	0.1		9	0.0	
4	1.0	0.6	12	0.8	0.5
5	2.2	1.6	15	1.9	1.4
6	3.6	2.9	18	3.2	2.5
7	5.2	4.3	21	4.7	3.8
8	7.1	6.0	24	6.4	5.4
9	9.3	7.9	27	8.4	7.1
10	11.7	10.0	30	10.6	9.1
11	14.4	12.4	33	13.0	11.2
12	17.3	15.0	36	15.7	13.6
13	20.5	17.8	39	18.6	16.1
14	24.0	20.8	42	21.7	18.9
15	27.6	24.1	45	25.1	21.8
16	31.6	27.5	48	28.7	25.0
17	35.8	31.2	51	32.5	28.4
18	40.3	35.1	54	36.6	32.0
19	45.0	39.3	57	40.9	35.7
20	49.9	43.7	60	45.4	39.7
21	55.2	48.3	63	50.2	43.9
22	60.6	53.1	66	55.2	48.3
23	66.4	58.1	69	60.4	52.9
24	72.3	63.4	72	65.9	57.7
25	78.6	68.9	75	71.6	62.7
26	85.1	74.6	78	77.5	67.9
27	91.8	80.5	81	83.6	73.4
28	98.8	86.7	84	90.0	79.0
29	106.1	93.1	87	96.6	84.8
30	113.6	99.7	90	103.5	90.8
			93	110.6	97.5

**Appendix V. Keora (*Sonneratia apetala* Buch. - Ham.) in the plantations of Noakhali, Bhola and Patuakhali Coastal areas, Total volume overbark in cubic feet for dbh/gbh in inches and height in feet**

DBH (in)	GBH (in)	Height in meters						
		15	25	35	45	55	65	75
3	9	0.7	0.9	1.0	1.2	1.4	1.6	1.7
4	13	0.9	1.2	1.5	1.8	2.1	2.4	2.7
5	16	1.1	1.6	2.1	2.6	3.1	3.6	4.1
6	19	1.5	2.2	2.9	3.6	4.3	5.0	5.7
7	22	1.8	2.8	3.8	4.7	5.7	6.6	7.6
8	25	2.3	3.5	4.8	6.0	7.3	8.5	9.8
9	28	2.8	4.4	5.9	7.5	9.1	10.7	12.2
10	31	3.3	5.3	7.2	9.2	11.1	13.1	15.0
11	35	3.9	6.3	8.7	11.0	13.4	15.7	18.1
12	38	4.6	7.4	10.2	13.0	15.8	18.6	21.4
13	41	5.3	8.6	11.9	15.2	18.5	21.8	25.1
14	44	6.1	9.9	13.8	17.6	21.4	25.2	29.0
15	47	7.0	11.4	15.7	20.1	24.5	28.9	33.3
16	50	7.9	12.9	17.8	22.8	27.8	32.8	37.8
17	53	8.8	14.5	20.1	25.7	31.3	37.0	42.6
18	57	9.9	16.2	22.5	28.8	35.1	41.4	47.7
19	60	11.0	18.0	25.0	32.0	39.1	46.1	53.1
20	63	12.1	19.9	27.7	35.4	43.2	51.0	58.8
21	66	13.3	21.9	30.4	39.0	47.6	56.2	64.8
22	69	14.5	24.0	33.4	42.8	52.2	61.6	71.1
23	72	15.9	26.1	36.4	46.7	57.0	67.3	77.6
24	75	17.2	28.4	39.6	50.9	62.1	73.3	84.5

**Appendix VI. Keora (*Sonneratia apetala* Buch. - Ham.) in the plantations of Noakhali, Bhola and Patuakhali Coastal areas. Total volume underbark to a top end diameter of 3.0 inches overbark in cubic feet for dbh/gbh in inches and height in feet**

DBH (in)	GBH (in)	Height in feet						
		15	25	35	45	55	65	75
3	9	0.4	0.5	0.7	0.8	1.0	1.2	1.3
4	13	0.6	0.8	1.1	1.4	1.7	1.9	2.2
5	16	0.8	1.2	1.7	2.1	2.5	2.9	3.4
6	19	1.1	1.7	2.3	2.9	3.6	4.2	4.8
7	22	1.4	2.3	3.1	3.9	4.8	5.6	6.5
8	25	1.8	2.9	4.0	5.1	6.2	7.3	8.4
9	28	2.2	3.6	5.0	6.4	7.8	9.2	10.6
10	31	2.7	4.5	6.2	7.9	9.6	11.3	13.1
11	35	3.3	5.4	7.4	9.5	11.6	13.7	15.8
12	38	3.9	6.3	8.8	11.3	13.8	16.3	18.8
13	41	4.5	7.4	10.3	13.2	16.2	19.1	22.0
14	44	5.2	8.6	12.0	15.3	18.7	22.1	25.5
15	47	6.0	9.8	13.7	17.6	21.5	25.3	29.2
16	50	6.8	11.2	15.6	20.0	24.4	28.8	33.2
17	53	7.6	12.6	17.6	22.6	27.5	32.5	37.5
18	57	8.5	14.1	19.7	25.3	30.8	36.4	42.0
19	60	9.5	15.7	21.9	28.1	34.4	40.6	46.8
20	63	10.5	17.4	24.3	31.2	38.1	44.9	51.8
21	66	11.5	19.1	26.7	34.3	41.9	49.5	57.1
22	69	12.7	21.0	29.3	37.7	46.0	54.4	62.7
23	72	13.8	22.9	32.0	41.2	50.3	59.4	68.5
24	75	15.0	25.0	34.9	44.8	54.7	64.7	74.6

**Appendix VII. Keora (*Sonneratia apetala* Buch. - Ham.) in the plantations of Chittagong Coastal areas, Total volume overbark and total volume underbark to a top end diameter of 7.0 cm overbark in cubic meters for dbh/gbh in centimeters**

DBH (cm)	V <sub>ctm1</sub> (m <sup>3</sup> )	V <sub>cum1</sub> (m <sup>3</sup> )	GBH (cm)	V <sub>ctm1</sub> (m <sup>3</sup> )	V <sub>cum1</sub> (m <sup>3</sup> )
8	0.009		25	0.009	
10	0.027	0.019	30	0.023	0.015
12	0.049	0.038	35	0.039	0.029
14	0.075	0.060	40	0.058	0.046
16	0.105	0.086	45	0.080	0.064
18	0.139	0.116	50	0.104	0.085
20	0.177	0.149	55	0.130	0.108
22	0.219	0.186	60	0.159	0.134
24	0.265	0.226	65	0.191	0.161
26	0.315	0.269	70	0.225	0.191
28	0.369	0.316	75	0.262	0.223
30	0.427	0.367	80	0.301	0.257
32	0.489	0.421	85	0.343	0.294
34	0.555	0.478	90	0.387	0.332
36	0.625	0.539	95	0.434	0.373
38	0.699	0.604	100	0.483	0.416
40	0.777	0.672	105	0.535	0.461
42	0.859	0.743	110	0.589	0.509
44	0.945	0.818	115	0.646	0.558
46	1.035	0.897	120	0.706	0.610
48	1.129	0.978	125	0.768	0.664
50	1.227	1.064	130	0.832	0.720
			135	0.899	0.779
			140	0.969	0.839
			145	1.041	0.902
			150	1.116	0.967
			155	1.193	1.035

**Appendix VIII. Keora (*Sonneratia apetala* Buch. - Ham.) in the plantations of Chittagong Coastal areas, Total volume overbark in cubic meters for dbh/gbh in centimeters and height in meters**

DBH (cm)	GBH (cm)	Height in meters						
		4	7	10	13	16	19	22
8	25	0.016	0.022	0.029	0.035	0.041	0.048	0.054
10	31	0.021	0.031	0.041	0.051	0.060	0.070	0.080
12	38	0.026	0.041	0.055	0.070	0.084	0.098	0.113
14	44	0.033	0.053	0.072	0.092	0.112	0.131	0.151
16	50	0.041	0.067	0.092	0.118	0.143	0.169	0.195
18	57	0.050	0.083	0.115	0.147	0.180	0.212	0.244
20	63	0.060	0.100	0.140	0.180	0.220	0.260	0.300
22	69	0.072	0.120	0.168	0.216	0.265	0.313	0.361
24	75	0.084	0.141	0.199	0.256	0.314	0.371	0.429
26	82	0.097	0.165	0.232	0.299	0.367	0.434	0.502
28	88	0.112	0.190	0.268	0.346	0.424	0.502	0.581
30	94	0.127	0.217	0.306	0.396	0.486	0.576	0.665
32	101	0.143	0.246	0.348	0.450	0.552	0.654	0.756
34	107	0.161	0.276	0.392	0.507	0.622	0.737	0.853
36	113	0.180	0.309	0.438	0.567	0.697	0.826	0.955
38	119	0.199	0.343	0.487	0.631	0.775	0.919	1.063
40	126	0.220	0.380	0.539	0.699	0.858	1.018	1.177
42	132	0.242	0.418	0.594	0.770	0.945	1.121	1.297
44	138	0.265	0.458	0.651	0.844	1.037	1.230	1.423
46	145	0.289	0.500	0.711	0.922	1.133	1.344	1.555
48	151	0.314	0.543	0.773	1.003	1.233	1.462	1.692
50	157	0.340	0.589	0.838	1.088	1.337	1.586	1.836

**Appendix IX. Keora (*Sonneratia apetala* Buch. - Ham.) in the plantations of Chittagong Coastal areas, Total volume underbark to a top end diameter of 7.0 cm overbark in cubic meters for dbh/gbh in centimeters and height in meters**

DBH (cm)	GBH (cm)	Height in meters						
		4	7	10	13	16	19	22
8	25	0.007	0.012	0.018	0.024	0.030	0.035	0.041
10	31	0.011	0.020	0.029	0.038	0.047	0.056	0.064
12	38	0.016	0.029	0.042	0.055	0.068	0.080	0.093
14	44	0.022	0.040	0.057	0.075	0.092	0.110	0.127
16	50	0.030	0.052	0.075	0.098	0.121	0.144	0.166
18	57	0.038	0.066	0.095	0.124	0.153	0.182	0.211
20	63	0.047	0.082	0.118	0.154	0.189	0.225	0.260
22	69	0.057	0.100	0.143	0.186	0.229	0.272	0.315
24	75	0.068	0.119	0.170	0.222	0.273	0.324	0.375
26	82	0.079	0.140	0.200	0.260	0.320	0.381	0.441
28	88	0.092	0.162	0.232	0.302	0.372	0.442	0.511
30	94	0.106	0.186	0.266	0.347	0.427	0.507	0.587
32	101	0.121	0.212	0.303	0.394	0.486	0.577	0.668
34	107	0.136	0.239	0.342	0.445	0.548	0.651	0.754
36	113	0.153	0.269	0.384	0.500	0.615	0.730	0.846
38	119	0.171	0.299	0.428	0.557	0.685	0.814	0.943
40	126	0.189	0.332	0.474	0.617	0.759	0.902	1.045
42	132	0.209	0.366	0.523	0.680	0.837	0.995	1.152
44	138	0.229	0.402	0.574	0.747	0.919	1.092	1.264
46	145	0.251	0.439	0.628	0.816	1.005	1.193	1.382
48	151	0.273	0.478	0.683	0.889	1.094	1.299	1.505
50	157	0.296	0.519	0.742	0.964	1.187	1.410	1.633

**Appendix X. Keora (*Sonneratia apetala* Buch. - Ham.) in the plantations of Chittagong Coastal areas, Total volume under and total volume underbark to a top end diameter of 7.0 cm overbark in cubic meters for dbh/gbh in inches**

DBH (in)	V <sub>cti1</sub> (ft <sup>3</sup> )	V <sub>cui1</sub> (ft <sup>3</sup> )	GBH (in)	V <sub>cti1</sub> (ft <sup>3</sup> )	V <sub>cui1</sub> (ft <sup>3</sup> )
3	0.2		9	0.2	
4	1.1	0.7	12	0.9	0.6
5	2.1	1.6	15	1.8	1.4
6	3.4	2.7	18	3.0	2.4
7	4.8	4.1	21	4.3	3.6
8	6.6	5.6	24	5.9	5.0
9	8.5	7.3	27	7.7	6.6
10	10.7	9.3	30	9.7	8.3
11	13.1	11.4	33	11.8	10.3
12	15.8	13.8	36	14.2	12.4
13	18.6	16.3	39	16.9	14.7
14	21.8	19.1	42	19.7	17.2
15	25.1	22.0	45	22.7	19.9
16	28.7	25.2	48	25.9	22.8
17	32.4	28.6	51	29.4	25.9
18	36.5	32.1	54	33.0	29.1
19	40.7	35.9	57	36.9	32.5
20	45.2	39.9	60	41.0	36.2
21	49.9	44.1	63	45.3	40.0
22	54.9	48.4	66	49.7	43.9
23	60.0	53.0	69	54.4	48.1
24	65.5	57.8	72	59.3	52.5
			75	64.5	57.0

**Appendix XI. Keora (*Sonneratia apetala* Buch. - Ham) in the plantations of Chittagong Coastal areas, Total volume overbark in cubic feet for dbh/gbh in inches and height in feet**

DBH (in)	GBH (in)	Height in feet						
		15	25	35	45	55	65	75
3	9	0.6	0.8	1.0	1.2	1.4	1.6	1.8
4	13	0.8	1.2	1.6	1.9	2.3	2.7	3.0
5	16	1.1	1.7	2.3	2.9	3.4	4.0	4.6
6	19	1.5	2.3	3.2	4.0	4.8	5.7	6.5
7	22	2.0	3.1	4.2	5.3	6.5	7.6	8.7
8	25	2.5	4.0	5.4	6.9	8.4	9.9	11.3
9	28	3.1	4.9	6.8	8.7	10.5	12.4	14.3
10	31	3.7	6.0	8.3	10.6	13.0	15.3	17.6
11	35	4.4	7.2	10.0	12.8	15.6	18.4	21.2
12	38	5.2	8.6	11.9	15.2	18.5	21.9	25.2
13	41	6.1	10.0	13.9	17.8	21.7	25.6	29.5
14	44	7.0	11.6	16.1	20.6	25.1	29.7	34.2
15	47	8.0	13.2	18.4	23.6	28.8	34.0	39.2
16	50	9.1	15.0	20.9	26.8	32.8	38.7	44.6
17	53	10.3	16.9	23.6	30.3	36.9	43.6	50.3
18	57	11.5	19.0	26.4	33.9	41.4	48.9	56.3
19	60	12.8	21.1	29.4	37.8	46.1	54.4	62.7
20	63	14.1	23.3	32.6	41.8	51.0	60.3	69.5
21	66	15.5	25.7	35.9	46.1	56.2	66.4	76.6
22	69	17.0	28.2	39.4	50.5	61.7	72.9	84.0
23	72	18.6	30.8	43.0	55.2	67.4	79.6	91.8
24	75	20.2	33.5	46.8	60.1	73.4	86.7	100.0

**Appendix XII. Keora (*Sonneratia apetala* Buch. - Ham.) in the plantations of Chittagong Coastal areas, Total volume underbark to a top end diameter of 3.0 inches overbark in cubic feet for dbh/gbh in inches and height in feet**

DBH (in)	GBH (in)	Height in feet						
		15	25	35	45	55	65	75
3	9	0.2	0.4	0.6	0.8	1.0	1.2	1.4
4	13	0.5	0.8	1.1	1.5	1.8	2.1	2.4
5	16	0.7	1.3	1.8	2.3	2.8	3.3	3.8
6	19	1.1	1.8	2.6	3.3	4.1	4.8	5.5
7	22	1.5	2.5	3.5	4.5	5.5	6.5	7.6
8	25	2.0	3.3	4.6	5.9	7.2	8.6	9.9
9	28	2.5	4.2	5.8	7.5	9.2	10.8	12.5
10	31	3.1	5.1	7.2	9.3	11.3	13.4	15.5
11	35	3.7	6.2	8.7	11.2	13.7	16.2	18.7
12	38	4.4	7.4	10.4	13.3	16.3	19.3	22.3
13	41	5.2	8.7	12.2	15.7	19.2	22.7	26.1
14	44	6.0	10.1	14.1	18.2	22.2	26.3	30.3
15	47	6.9	11.6	16.2	20.9	25.5	30.2	34.8
16	50	7.9	13.2	18.5	23.8	29.0	34.3	39.6
17	53	8.9	14.9	20.9	26.8	32.8	38.8	44.7
18	57	10.0	16.7	23.4	30.1	36.8	43.5	50.1
19	60	11.2	18.6	26.1	33.5	41.0	48.4	55.9
20	63	12.4	20.6	28.9	37.1	45.4	53.7	61.9
21	66	13.6	22.7	31.8	40.9	50.1	59.2	68.3
22	69	15.0	25.0	34.9	44.9	54.9	64.9	74.9
23	72	16.4	27.3	38.2	49.1	60.0	71.0	81.9
24	75	17.8	29.7	41.6	53.5	65.4	77.3	89.2

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

**M. A. Latif, S. Das, M. F. Rahman and J. A. Chowdhury**

### **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	
<b>TOTAL</b>	<b>17</b>	<b>48</b>	<b>66</b>	<b>77</b>	<b>62</b>	<b>23</b>	<b>12</b>	<b>2</b>	<b>1</b>	<b>308</b>	

## 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.

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.

## 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.  $V = b_0 + b_1 D^2 + b_2 H + b_3 D^2 H$

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 <sup>2</sup>	F	F. I.
V <sub>mo1</sub> = b <sub>0</sub> + b <sub>1</sub> *D <sup>2</sup>	0.00039	0.790	1031.47	0.0197
V <sub>mu1</sub> = b <sub>0</sub> + b <sub>1</sub> *D <sup>2</sup>	0.00038	0.760	869.98	0.0196
V <sub>mo2</sub> = b <sub>0</sub> + b <sub>1</sub> *D <sup>2</sup> *H	0.00026	0.859	1672.16	0.0161
V <sub>mu2</sub> = b <sub>0</sub> + b <sub>1</sub> *D <sup>2</sup> *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 <sup>2</sup>				
	t	%AD	F	t	F	t	t	Slope	
V <sub>mo1</sub> = b <sub>0</sub> + b <sub>1</sub> *D <sup>2</sup>	0.208	1.1	0.4157	0.329	5.38	0.40	2.18	44.0	
V <sub>mu1</sub> = b <sub>0</sub> + b <sub>1</sub> *D <sup>2</sup>	0.300	2.0	0.3934	0.334	4.05	0.42	2.61	43.7	
V <sub>mo2</sub> = b <sub>0</sub> + b <sub>1</sub> *D <sup>2</sup> *H	0.377	1.6	0.0295	0.320	0.62	0.29	2.08	44.9	
V <sub>mu2</sub> = b <sub>0</sub> + b <sub>1</sub> *D <sup>2</sup> *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 :

#### METRIC UNITS

Total volume overbark for one way :

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

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

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

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

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

Total volume overbark for two way :

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

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

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

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

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

#### IMPERIAL UNITS

Total volume overbark for one way :

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

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

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

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

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

Total volume overbark for two way :

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

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

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

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

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

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 outside the height and dbh ranges shown in the stand table should only be done with caution.

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**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 <sup>3</sup> )	Dbh (in)	Gbh (in)	Volume (ft <sup>3</sup> )
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 GBH		Height in feet								
(in)	(in)	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	