GROWTH AND YIELD OF KEORA *(SONNERATIA APETALA)* IN THE COASTAL PLANTATIONS OF BANGLADESH

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ABSTRACT

Keora (*Sonneratia apetala* Buch.-Ham.) is the principal plantation species in the coastal areas of Bangladesh. A yield prediction model was developed for keora plantations by regression techniques using the dominant height attained at a reference age of 12 years. The model composed of four equations : stand dominant height equation, stand mean diameter equation, stand basal area equation and stand volume yield equation. The proposed model was verified using a separate set of data from 30 sample plots. This model was found to be suitable for estimating growth and yield of keora in the coastal plantations of Bangladesh.

সারসংক্ষেপ

বাংলাদেশের উপকূলীয় এলাকা বনায়নে কেওড়া প্রধান প্রজাতির গাছ। উপকূলীয় এলাকায় এই প্রজাতির বর্ধনহার ও উৎপাদন ক্ষমতা নির্ণয়ের জন্য রিগ্রেশন পদ্ধতিতে মডেল প্রস্তুত করা হইয়াছে। মডেল প্রণয়নে ১২ বৎসর বয়সের কেওড়া গাছের সর্বোচ্চ উচ্চতাকে রেফারেন্স হিসাবে ধরা হয়। স্ট্যান্ড সর্বোচ্চ উচ্চতা, স্ট্যান্ড গড় ব্যাস, স্ট্যান্ড ব্যাসাল এরিয়া ও স্ট্যান্ড উৎপাদন সমীকরণ –এই চারটি সমীকরণের সমন্বয়ে প্রস্তাবিত মডেল প্রণীত হয়। ত্রিশটি নমুনা প্লটের উপাত্ত ব্যবহার করিয়া উপরোক্ত মডেলের যথার্থতা যাচাই করা হয়। মডেলটি বাংলাদেশের উপকূলীয় কেওড়া বনের বর্ধনহার ও উৎপাদন ক্ষমতা নির্ণয়ে উপযুক্ত প্রমাণিত হইয়াছে।

INTRODUCTION

The important factors on which the yield depends are age, site quality and stand density. These factors are used along with their log and reciprocal transformations, and probable combinations either in the original or in the transformed forms for estimating growth and yield of forestry species (Leak 1970, Pimmanrojnagool 1979, Monoy 1981, Gregorio 1981, Revilla and Gregorio 1982, Gonzales 1985).

Keora (*Sonneratia apetala* Buch.-Ham.) is the principal species planted along the coastal areas of Bangladesh. This species has been planted since 1967. Information on growth rates and probable yield are lacking for the species from Bangladesh. This information is essential in preparing the management plans. Therefore, growth and yield models for keora in the coastal plantations in Bangladesh have been developed and presented in this paper.

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MATERIALS AND METHODS

The study was conducted in four Coastal Afforestation (CA) Divisions, namely, Chittagong, Noakhali, Barisal and Patuakhali and covering the age range of 0.5 to 19.5 years. Multistage stratified cluster sampling was done for the study. From each division, 2-4 forest ranges with plantations having maximum age ranges were selected. For each plantation year, two plantations were selected at random in each division from the selected range. Each plantation was divided into three strata based on the canopy density. The canopy density was divided into following three classes represented by the crown coverage as the percentage of the area :

Density classes	Crown coverage
1	> 70%
2	30-70%
3	< 30%

Data were collected from the density class 1 and 2 only. Density class 3 was considered as a failure plantation and no data was collected from that one.

A sufficient number of points was randomly selected on 1:10,000 maps before field work was started. The locations of the points in the forests were selected by moving to appropriate directions and distances from easily identifiable landmarks on both maps and the ground. The location thus selected was the centre of the first sub plot.

Subsequently, two more sub plots were chosen 30 meters apart, one in the direction of the nearest water source and the other opposite the water source. These three sub plots constituted one sample plot. The sub plots were squares of 0.01 ha each; thus the total area of a sample plot was 0.03 ha. Data on diameters at breast height (dbh), dominant height, and the heights of all the trees were collected from a total of 263 sample plots.

Diameters at breast height (dbh) were measured by a diameter tape and corrected to the nearest 0.1 cm for all the trees in the sample plot. The total height of the tallest tree in each sub plot was measured by a measuring stick and corrected to 0.1 m for the plots with dominant height of 8.0 m or less, and by Blume Leiss hypsometer, corrected to the nearest 0.5 m for the plots with larger trees. The heights of the other trees were estimated from the height of the trees measured.

Data collation : The volume of the individual tree was estimated by using the volume equations for the species (Drigo *et al.* 1987). For the selection of the best suited site index guide equation, the following models were tested :

1. $\log(H) = b_0 + b_1 \log(A)$
2. $\log(H) = b_0 + b_1/A^k, 0.2 \leq k \leq 2.0$
3. $H = b_2 * (1 - e^{-b1*A})^{b3}$

where, b_0 = intercept
b_1 = slope
b_2 = asymptote
b_3 = inflection point
H = mean height of 100 dominant and codominant trees per hectare
A = age of the plantation in years

Among the above mentioned models, the best suited model was selected subject to the fulfilment of the statistical and biological requirements.

For statistical processing, information was derived for stand age (A), dbh of the mean basal area tree (D), average total height (H), basal area/ha (B), volume/ha (V), site index (S), and spacing (P).

For the determination of the best suited yield equations, the site index equation was derived first. This was followed by the derivation of stand dbh equation, stand basal area equation, and stand volume yield equation. Backward selection method and all probable combinations of the independent variables method were used to select the best suited model subject to the satisfaction of the statistical and biological requirements.

MODEL VALIDATION

Statistical validation : Statistical validation was the first step done in validating the models. It included the analyses of variance, minimum residual mean square, the highest coefficient of determination (R^2) and the highest adjusted R^2.

Biological principal testing : The predicted values were plotted against age for different site indices. The biological requirement is that the yield curves should be sigmoid or S-shaped.

Independent test : Validation of the models was done by using data from 30 separate sample plots. This was done by comparing the estimated and observed values applying the chi-square test of goodness of fit and paired t-test. These were also compared with 45 degree line test by plotting the observed values and the predicted value in the graph.

RESULTS AND DISCUSSIONS

The site index model 3 was found to be suitable for keora in the coastal plantations in Bangladesh. The specific form of the equation is given by

$$H = 20 * (1 - e^{-0.0988*A})1.2$$
$$R^2 = 0.68$$

The mean sum of squares for site index guide equation is given in Table 1.

To obtain the site index for each plot, a reference age of 12 years was used and the specific equation is given below :

$$H = 1.5488* S* (1-e^{-0.0988*A})1.2$$

where, S = site index of an individual sample plot in meters at the base age of 12 years.

The mean dominant height growth of keora at different site indices is given in Fig. 1

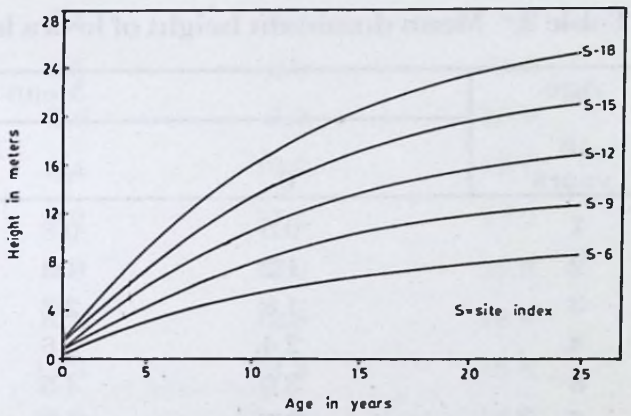

Figure 1. Stand dominant height growth curves for keora in coastal affo restations in Bangladesh

The selected stand diameter (D), stand basal area (B) and volume yield (V) equations along with the corresponding coefficient of determinations are given below :

$\log (D) = 0.10 *S/A - 4.613/A+0.391* \log (A) + 0.695 * \log (S)$

$R^2 = 0.97$

$\log (B) = 3.2465 + 0.0341 * S - 13.5952/A + 0.4107* S/A$

$R^2 = 0.963$

$\log (V) = 4.6147 + 0.0549*S - 17.2626/A + 0.5988* S/A$

$R^2 = 0.963$

The mean sum of squares for stand diameter growth, stand basal area and volume yield equations are given in Table 1.

Table 1. Mean sum of squares for site index guide, stand diameter growth, stand basal area and volume yield equations for keora grown in the coastal plantations of Bangladesh

SV	df	Site index equation	Stand Diameter	Stand Basal area	Volume yield
Regression	3	39.89*	337.26 *	1160.07*	1357.58*
Residual	259	0.07	10.313	44.39	52.59

* *significant at 0.001 level of probability.*

Table 2. Mean dominant height of keora in the coastal plantations of Bangladesh

Age in years	Mean dominant height in meters				
	Site indices in meters				
	6	9	12	15	18
1	0.5	0.8	1.1	1.4	1.6
2	1.2	1.8	2.4	3.0	3.5
3	1.8	2.7	3.6	4.5	5.4
4	2.4	3.6	4.9	6.1	7.3
5	3.0	4.5	6.0	7.5	9.0
6	3.5	5.3	7.1	8.8	10.6
7	4.0	6.1	8.1	10.1	12.1
8	4.5	6.7	9.0	11.2	13.5
9	4.9	7.4	9.8	12.3	14.8
10	5.3	8.0	10.6	13.3	15.9
11	5.7	8.5	11.3	14.2	17.0
12	6.0	9.0	12.0	15.0	18.0
13	6.3	9.4	12.6	15.7	18.9
14	6.6	9.9	13.1	16.4	19.7
15	6.8	10.2	13.6	17.1	20.5
16	7.0	10.6	14.1	17.6	21.1
17	7.3	10.9	14.5	18.1	21.8
18	7.4	11.2	14.9	18.6	22.3
19	7.6	11.4	15.2	19.0	22.8
20	7.8	11.7	15.5	19.4	23.3
21	7.9	11.9	15.8	19.8	23.7
22	8.0	12.1	16.1	20.1	24.1
23	8.2	12.2	16.3	20.4	24.5
24	8.3	12.4	16.5	20.7	24.8
25	8.4	12.5	16.7	20.9	25.1

Table 3. Mean stand diameter for keora in the coastal plantations of Bangladesh

Age in years	Mean stand diameter in cm				
	Site indices in meters				
	6	9	12	15	18
1	0.1	0.1	0.2	0.3	0.5
2	0.6	1.0	1.4	1.9	2.6
3	1.4	2.1	2.9	3.7	4.7
4	2.2	3.2	4.2	5.3	6.6
5	2.9	4.2	5.4	6.8	8.2
6	3.6	5.1	6.5	8.0	9.6
7	4.2	5.9	7.5	9.2	10.9
8	4.8	6.6	8.4	10.2	12.0
9	5.3	7.3	9.2	11.1	13.1
10	5.7	7.9	9.9	12.0	14.0
11	6.2	8.4	10.6	12.8	14.9
12	6.6	9.0	11.3	13.5	15.8
13	7.0	9.5	11.9	14.2	16.6
14	7.3	10.0	12.5	14.9	17.3
15	7.7	10.4	13.0	15.5	18.0
16	8.0	10.8	13.5	16.1	18.7
17	8.3	11.3	14.0	16.7	19.3
18	8.6	11.6	14.5	17.2	19.9
19	8.9	12.0	14.9	17.7	20.5
20	9.2	12.4	15.4	18.2	21.0
21	9.5	12.7	15.8	18.7	21.6
22	9.7	13.1	16.2	19.2	22.1
23	10.0	13.4	16.6	19.6	22.6
24	10.2	13.7	17.0	20.1	23.1
25	10.4	14.0	17.3	20.5	23.6

Table 4. Mean volume yield for keora in the coastal areas of Bangladesh

Age in years	Mean volume yield (cu m /ha)				
	Site indices in meters				
	6	9	12	15	18
1	0.00	0.00	0.01	0.06	0.41
2	0.15	0.44	1.27	3.66	10.61
3	1.47	3.16	6.79	14.57	31.26
4	4.60	8.51	15.72	29.04	53.66
5	9.12	15.40	26.02	43.94	74.21
6	14.38	22.88	36.40	57.91	92.12
7	19.92	30.36	46.27	70.53	107.50
8	25.42	37.53	55.39	81.76	120.69
9	30.74	44.25	63.71	91.73	132.06
10	35.78	50.50	71.26	100.57	141.93
11	40.52	56.25	78.10	108.43	150.55
12	44.94	61.55	84.29	115.45	158.13
13	49.05	66.41	89.92	121.75	164.84
14	52.88	70.89	95.04	127.41	170.81
15	56.43	75.1	99.71	132.54	176.17
16	59.74	78.82	103.98	137.19	180.99
17	62.82	82.33	107.91	141.43	185.36
18	65.69	85.59	111.52	145.31	189.33
19	68.37	88.62	114.96	148.87	192.95
20	70.87	91.43	117.94	152.15	196.27
21	73.22	94.05	120.81	155.18	199.33
22	75.42	96.50	123.47	157.98	202.15
23	77.48	98.97	125.95	160.59	204.75
24	79.42	100.94	128.28	163.02	207.17
25	81.25	102.95	130.45	165.28	209.42

The stand diameter growth equation explains 97.0% of the total variation. Both the stand basal area and volume yield equations explain 96.3% of the total variation leaving only 3.7% unexplained. The mean volume yield per hectare growth curves are given in Figure 2.

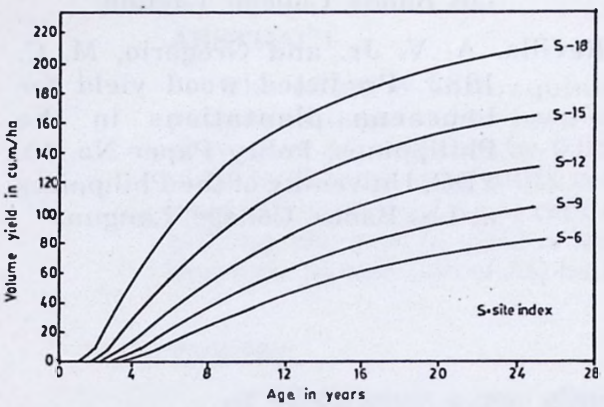

Figure 2. Stand volume yield growth curves for keora in coastal afforestations in Bangladesh

Statistical validation and biological principal testing : The selected models statisfied all the statistical criteria. The predicted values were plotted against age for different site indices. The curves were found to conform with the ideal attributes of a biological yield curve. The yield curves were sigmoid or S-shaped. The yield curves also show that at a given stand age, higher yield is expected on better sites.

Independent test : The computed chi-square and t - values for dbh, basal area, and volume yield are given below :

Variable	Chi-square value	t-value
dbh	3.375	0.0072
basal area/ha	11.827	0.1491
volume yield/ha	12.178	0.0944

The computed chi-square and t values were less than the tabular values ($X^2_{0.95,29} = 17.71$ and $t_{0.95,29} = 2.045$). These imply that there is no significant difference between the actual values from the 30 test sample plots and their corresponding expected values as predicted by the models. Hence, the selected models conform with the set of data.

45 degree line test : Graphs comparing the observed values and the predicted values were ploted in the graphs It was observed that the models tend to make an angle of 45 degrees with the axes, meaning there is no significant difference between the actual and the predicted values.

After the validation test, stand dominant height, stand diameter and stand volume yield per hectare were estimated and presented in Tables 2, 3 and 4 respectively.

The yield prediction model derived in the study could be statisfactorily used for keora plantations within the limitations of the data used in the study. The yield prediction function and its use is recommended for stands of ages 3-20 years and site indices of 4.5 to 18.4 meters based on a base age of 12 years.

REFERENCES

Drigo, R.; Latif, M. A.; Chowdhury, J. A. and Shaheduzzaman, M. 1987. The maturing mangrove plantation of the coastal afforestation project. FAO/UNDP Project BGD/85/085. Assistance to the Forestry Sector. 69 pp.

Gonzales, L. L. 1985. Growth and yield prediction model for teak (*Tectona grandis* Linn.) plantations. M. S. Thesis. University of the

Philippines at Los Banos, College, Laguna

Gregorio, M. C. 1981. Growth and yield prediction models for yemane (*Gmelina arborea* Roxb.). M. S. Thesis. College of Forestry, University of the Philippines at Los Banos, College, Laguna

Leak, W. 1970. Yield of easter white pine in New England related to age, site and stocking. USDA Forest Service Research Paper NF-176. 75 pp.

Monoy, R. E. 1981. A yield prediction model for giant ipil-ipil (*Leucaena leucocephala* Lam. De Wit.). M. S. Thesis. College of Forestry, University of the Philippines at Los Banos, College, Laguna

Pimmanrojnagool, V. 1979. A yield prediction model for *Pinus kesiya* plantations in Chiengmai, Thailand. Ph. D. Thesis. University of the Philippines at Los Banos, College, Laguna

Revilla. A. V. Jr. and Gregorio, M. C. 1982. Predicted wood yield for Leucaena plantations in the Philippines. Policy Paper No. 10. FDC, University of the Philippines at Los Banos, College, Languna