Forest Growth Simulation: Tropical Rain Forest Stand Table Projection

Yasmin Yahya, Roslan Ismail, Samreth Vanna and Khorn Saret

Abstract—The study on the tree growth for four species groups of commercial timber in Koh Kong province, Cambodia's tropical rainforest is described. The simulation for these four groups had been successfully developed in the 5-year interval through year-60. Data were obtained from twenty permanent sample plots in the duration of thirteen years. The aim for this study was to develop stand table simulation system of tree growth by the species group. There were five steps involved in the development of the tree growth simulation: aggregate the tree species into meaningful groups by using cluster analysis; allocate the trees in the diameter classes by the species group; observe the diameter movement of the species group. The diameter growth rate, mortality rate and recruitment rate were calculated by using some mathematical formula. Simulation equation had been created by combining those parameters. Result showed the dissimilarity of the diameter growth among species groups.

Keywords—cluster analysis, diameter growth, simulation

I. INTRODUCTION

SIMULATION for forest growth plays an important role in forest management. It is a major key for developing long-term strategies for forest management and ensuring resource sustainability. It helps the forest management planning in decision making in improving logging system and reducing damage. There are a lot of simulation models had been developed by researchers which cover for uneven-aged and even-aged of individual tree and stand table. Every simulation model had its own unique and technique and will accommodate at specific places and tree species. Simulation model is produced by a combination of several models such as diameter increment, mortality and recruitment; furthermore, it is developed by different techniques. Vanclay, an experienced researcher described several techniques for modeling forest growth [5]. He mentioned the stand table projection had several advantages for growth and yield models for uneven-aged forests as it provide simple and computationally efficient.Researchers Palahi et al. developed simulation model to predict stand growth and yield of Scots pine stands in north-east Spain [1]. They developed stand density model, stand basal area model and volume model using non-linear three-stage least square techniques as the estimation procedure. Vanclay [2] used the technique of non-linear regression to predict diameter increment among the component trees. It was implemented as cohort models which consisted of stand basal area increment, diameter increment, mortality and regeneration.

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Huber and Sterba [3] applied growth simulator ProgAus to predict long term simulation of 23-plots of spruce-fir-beech for 1000 years. The system comprised of the individual-tree increment model, the crown ratio model and individual-tree height increment model. The results meet the expectations for the given district and site condition. Simulation models are not only developed for uneven-aged tree; in fact, many simulation models have been developed for even-age trees around the world. Miguel et al. [4] simulated the effect of future changes in site quality on the productivity of Pinus Brutia stand in Syria and Lebanon. They applied the technique of non-linear regression modeling. The significant variables to the models were site index, distance independent diameter increment, height, self thinning and country effects. The simulation produced mean annual increment and current annual increment curves which enable to predict optimal rotation length and site productivity.

Martinez et al. [6] emphasized on total volume increment and basal area ratio which significant to the stand growth model for Nothofagus pumilio. They fitted the model using statistical technique of non-linear regression which employed adjusted r-squared, standard error of estimation, mean absolute error and residual analysis to describe the model adjustment. Bjorn [7] constructed growth models to predict long term forest development. The models were separated by four functions; basal area growth function, height function, height growth function and volume function. Quang [8] investigated two methods for fitting the system of tree annual diameter growth and survival for individual tress from periodic measurements; averaging method and iterative method. The outcome proved iterative method provides better result.

There are various methods of estimating stand growth. Douglas et al. [9] pointed a method for estimating stand growth for four commercial tree species based on density measurement. They made comparison between tree spacing equation and diameter equation using regression analysis. The model equations were compiled to computer program using Microsoft Visual Basic; however, it worked best with even-aged stand. Researchers Sevillano et al. [10] developed a dynamic growth model with three variables significantly contributed to the models; stand basal area, number of trees per hectare and dominant height. The model was used for simulation the growth of radiate pine plantation in El Bierzo, Spain.

The objectives of this study were
- to aggregate the tree species into several groups
- to observe the growth of the tree species group at different diameter class
- to determine the diameter movement of tree species group
- to develop stand table simulation system of tree growth by species group

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II. MATERIAL AND METHOD

The study was carried out at twenty plots surrounding Koh Kong province, Cambodia. The area for each plot was approximately 1000 meter square. Number of trees varies from 16 to 54 trees per plot. Data were collected from 1998 to 2011 with the interval of two to five years. Data taken were diameter at breast height (dbh), tree number; plot number, species name and location of the tree (coordinate location based on the plot). The diameter at breast height of trees (dbh) was measured 1.3 meters above the ground. There were total of 627 live trees at the last re-measurement.

There were four measurements taken place which was in year 1998, 2000, 2005 and 2011. For every re-measurement, diameter at breast height was re-measured, dead trees and new trees were also recorded. The diameter of the trees for all four measurements were categorized into 17 diameter classes started with the first class "less than 7.5 cm", second class "7.5 - 9.9", third class "10 - 14.9" until the last diameter class of "more than 90 cm" with the class size of 5 cm.

Five steps involved in developing the simulation model
1. Aggregating trees species
2. Allocating trees in diameter classes by species groups
3. Observing the movement of the tree's diameter from one diameter class to higher diameter class
4. Calculating of diameter growth rate, mortality rate and recruitment rate
5. Creating simulation equation by combining the diameter growth rate, mortality rate and recruitment rate.

The growth of the diameter was observed for each re-measurement and recorded as whether the species stay at the same class, grow one class or grow two classes.

Annual diameter increment was calculated by subtracting the subsequence diameter size then dividing by the time (year) between two measurements; equation below refers to formula used for the annual diameter increment.

$$\Delta D = \frac{dbh_2 - dbh_1}{t}$$

Where
ΔD	=	Annual diameter increment
dbh_2	=	diameter at breast height at second measurement
dbh_1	=	diameter at breast height at first measurement

III. DATA ANALYSIS

Data collected were integrated in Microsoft Excel, then imported, coded and analyzed using statistical software namely Statistical Package for Social Science (SPSS), version 16.

A. Analysis of Species Structure Using Cluster Analysis

There are several hundred tree species exist in Cambodia tropical rainforests, of which majority are of commercial importance. Some species may have only a few trees belong to the group; this phenomenon will create bias estimation as the number of data is not sufficient. Besides, it is also not practical to develop separate functions for each tree species; hence, it is essential to group the tree species to smaller number of groups by some criteria such as diameter growth, average distance between trees and basal area. Vanclay [11] developed growth model for North Queensland rainforests had aggregated five tree species groups from hundreds of species. He classified the groups by three criteria which were volume relationship, logging practice and growth pattern. Shadrach [12] reported that the large tree species need to be aggregated into smaller group by certain methods. Different methods have their own strength and will produce different number of species group; however, he mentioned that cluster analysis is the most adequate since it ensures that species are classified according to the functions that drive the model rather than on ecophysiological attributes for which there is only little knowledge.

There are more than thirty tree species exist in this forest for which some species have the number of trees less than five. Species which have insufficient data for reliable parameter estimation will lead to bias prediction equations. The best way to avoid these phenomena to occur is to group the trees based on their similarity. One of the major techniques for classifying a huge of information into manageable meaningful quantities is cluster analysis. Cluster analysis is concerned with classification and there is no prior knowledge about which element belongs to which cluster. In this study hierarchical cluster analysis were carried out using Ward's method applying squared Euclidean distance as distance or similarity measure.

B. Stand Table Parameter

Stand table parameter needed the information about the percentage of tree movement into upper classes, the percentage of mortality and the percentage of recruitment.

C. Analysis of the Growth of Species Group by Diameter Interval Class

The growth of trees was observed at each of the re-measurement. The distribution of tree's diameter by species groups were recorded by diameter classes. The movement of the tree's diameter to upper diameter class was obtained by computing the difference between two subsequence interval classes. The percentage of tree movement was calculated by dividing the number of trees move by total number of trees within the same interval class; then multiply by hundred percent.

D. Calculation of Mortality Rate and Recruitment Rate

The number of trees dead and the growth of new trees (seedling and sapling) were observed at each re-measurement. Annual mortality rate and recruitment rate was calculated by dividing the number of dead trees or the number new recruitment by the total number of trees then multiply by hundred percent.

E. Stand Table Simulation

To obtain stand table simulation, basically two main tables were needed; stand table parameter and stand table inventory data.

Stand table parameter consists of information regarding percentage of tree's diameter movement; whether the diameter

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stays at the same interval class, move one class or move two classes. Mortality rate and recruitment rate were also kept in this table; whereas, stand table inventory data displayed the distribution of trees by interval classes. Both tables were separated by species groups.

The simulation was done in five-year interval. The formula for simulating the forest tree shown below:

For year 0, interval class $i = 1 \ldots i = 18$

$$N_{t=0} = N_i \text{ (as in the stand table)} \quad (1)$$

For year 5, number of trees in category stay, move 1-class, move 2-class and move 3-class are calculated by multiply the percentage of data in parameter table by the data in stand table.
When $i = 1$

$$N_{t=5,i} = N(\text{Stay})_i + N(\text{Re} \, cruitment)_i - N(\text{Mortality})_i \quad (2)$$

When $i = 2$

$$N_{t=5,i} = N(\text{Stay})_i + N(Grow \, 1-Class)_{i-1} - N(\text{Mortality})_i \quad (3)$$

When $i = 3$

$$N_{t=5,i} = N(\text{Stay})_i + N(Grow \, 1-Class)_{i-1} + N(Grow \, 2-Class)_{i-2} - N(\text{Mortality})_i \quad (4)$$

When $i = 4$ and above,

$$N_{t=5,i} = N(\text{Stay})_i + N(Grow \, 1-Class)_{i-1} + N(Grow \, 2-Class)_{i-2} + N(Grow \, 3-Class)_{i-3} \\ - N(\text{Mortality})_i \quad (5)$$

Where,

$N = $ total number of trees
$i = $ number of class interval; $i = 1, 2, 3, \ldots 18$
$t = $ year; $t = 10, 15, 20, \ldots 60$

For year 10 and above, number of trees in category stay, move 1-class, move 2-class and move 3-class are calculated by multiply the percentage of data in parameter table by the total number of trees in year before (t -5). The equation 2, 3, 4 and 5 are repeated to produce the total number of trees in each interval class.

IV. RESULT

Cluster analysis was done for which the grouping based on the diameter increment, basal area and average distance. Four species groups were suggested from the output of agglomeration schedule and dendogram. Table I displayed the distribution of trees by their respective group at the beginning of measurement. Species group 1 showed the highest number of trees as compared to other groups. The mean and standard deviation for diameter at breast height (dbh) for all species group were not significantly different; however, the maximum diameter was quite differing among groups. The largest trees belong to group 3 with maximum diameter of 91 cm. In addition, mortality rate was in the range of 5.12 % to 5.44%

and the number of seedling and sapling also vary from group to another group.

TABLE I
DISTRIBUTION OF TREE DIAMETER BY SPECIES GROUPS

	Group 1	Group 2	Group 3	Group 4
Mean	21.65	25.41	26.54	20.57
Std. dev	0.1105	0.191	0.162	0.134
Min	7.5	7.6	7.5	7.5
Max	56	87	91	61
N	273	102	135	117
N (Seedling)	1200	600	700	400
N (Sapling)	150	100	110	80
N (dead)	45	16	22	18
Mortality (per5-year)	5.44%	5.22%	5.39%	5.12%

The size of the trees for all species groups is approximately in the range of 7.5 cm to 91 cm where about ninety percent of the trees are below 45 cm. There are only two big size trees; one tree belong to group 2 with diameter interval of 85 to 90 cm and one tree from group 3 with diameter greater than 90 cm. The details of the distribution of trees diameter are illustrated in figure 1. As clearly shown in figure 1, species group 1 was the highest number in almost every diameter interval class. Although species group 2 was half of the number of group 1, its appearance was almost in all diameter interval class.
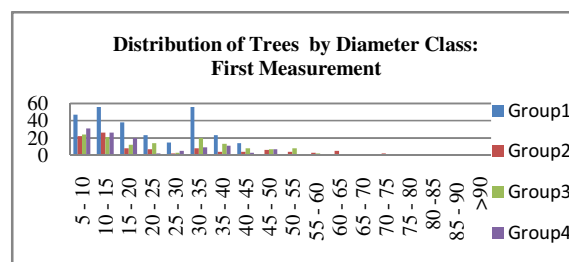

Fig. 1 Distribution of trees in diameter class by species groups

Table II to table V demonstrates the percentage of the tree movement from one diameter class to another diameter class throughout thirteen years period. Some trees are just stay at the same diameter class whereas some trees move one or two diameter classes; in fact, there are some trees are very fast growing in which they move three diameter classes. For all species groups, 70% to 80% of the trees stay at the first interval class and about 20% to 30% of the trees from this interval class move to the next diameter class. The trees size of 30 to 35 cm from specie group 1 showed rapidly growing where about 27% of them move one diameter class, 1% move 2 diameter classes and 0.6% move 3 diameter classes. Overall, the medium size of the trees (25 cm to 60 cm of diameter) for all species groups move to the next diameter class interval in the range of 20 % to 36%.

TABLE II
PARAMETER FOR SPECIES GROUP 1

Dia Class	% Stay	%Move 1-Class	%Move 2-Class	%Move 3-Class
5 - 10	69.5	30.5	0	0
10 - 15	78.57	21.43	0	0
15 - 20	70.18	29.43	0	0

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20 - 25	65.22	34.78	0	0
25 - 30	64.44	35.56	0	0
30 - 35	71.43	26.79	1.19	0.6
35 - 40	76.81	23.19	0	0
40 - 45	71.43	28.57	0	0
45 – 50	0	0	0	0
50 - 55	0	0	0	0
55 – 60	66.67	33.33	0	0
60 – 65	0	0	0	0
65 – 70	0	0	0	0
70 – 75	0	0	0	0
75 – 80	0	0	0	0
80 – 85	0	0	0	0
85 – 90	0	0	0	0
>90	0	0	0	0

TABLE III
PARAMETER FOR SPECIES GROUP 2

Dia Class	% Stay	%Move 1-Class	%Move 2-Class
5 - 10	78.79	21.21	0
10 - 15	89.74	8.33	0
15 - 20	91.67	8.33	0
20 - 25	90.48	9.52	0
25 - 30	83.33	16.67	0
30 - 35	83.33	16.67	0
35 - 40	66.67	25	8.33
40 - 45	75	25	0
45 - 50	50	50	0
50 - 55	100	0	0
55 – 60	66.67	33.33	0
60 – 65	73.33	26.67	0
65 – 70	0	0	0
70 – 75	100	0	0
75 – 80	0	0	0
80 – 85	0	0	0
85 – 90	100	0	0
>90	0	0	0

TABLE IV
PARAMETER FOR SPECIES GROUP 3

Dia Class	% Stay	%Move 1-Class	%Move 2-Class
5 - 10	80.56	19.44	0
10 - 15	84.13	15.87	0
15 - 20	80.56	19.44	0
20 - 25	80.95	19.05	0
25 - 30	77.78	22.22	0
30 - 35	83.33	16.67	0
35 - 40	82.05	15.38	2.56

40 - 45	75	25	0
45 - 50	85.71	14.29	0
50 - 55	70.83	29.17	0
55 – 60	83.33	16.67	0
60 – 65	66.67	33.33	0
65 – 70	100	0	0
70 – 75	0	0	0
75 – 80	0	0	0
80 – 85	0	0	0
85 – 90	0	0	0
>90	100	0	0

TABLE V
PARAMETER FOR SPECIES GROUP 4

Dia Class	% Stay	%Move 1-Class	%Move 2-Class
5 - 10	74.19	25.81	0
10 - 15	82.05	17.95	0
15 - 20	73.33	26.67	0
20 - 25	100	0	0
25 - 30	80	20	0
30 - 35	74.07	25.93	0
35 - 40	63.64	33.33	0
40 - 45	88.89	11.11	0
45 - 50	95.24	4.76	0
50 - 55	66.67	33.33	0
55 – 60	33.33	66.67	0
60 – 65	66.67	33.33	0
65 – 70	0	0	0
70 – 75	0	0	0
75 – 80	0	0	0
80 – 85	0	0	0
85 – 90	0	0	0
>90	0	0	0

Table VI displayed the simulation of the tree growth from initial year to year 60 for one of the four species group. The number of trees for species group 1 keeps increasing until year 20 due to high percentage of recruitment rate and low mortality rate, then it starts decreasing gradually until year 60. There are not many trees from this species group that fall under merchandize size after year 5 of simulation as the most of tree size at initial stage were small. Figure 2 (a – d) presented the simulation curves for all species groups. As can be seen, the curves showed the same pattern of exponential curve with slightly different towards the end of the diameter class interval. Group 1 and 3 showed a smooth curve while group 2 and 4 were smooth at the lower diameter class and became a bit crooked as a diameter class increased. For species group 2, the numbers of trees drastically increase until year 60 with 46% of increment. In addition, the trees with diameter class between 50cm to 55cm are also increase as the

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number of years increase. Species group 2 produces the largest number of trees from this interval class as compared to other groups. As for species group 3 and 4, the number of trees grow steadily until year 60 with rate of increment 36% and 18% respectively. Overall, for all species groups, most of the trees are within the diameter of below 40 cm for simulation up to 60 years.

TABLE VI
SIMULATION FOR SPECIES GROUP 1

Year	Seedling	Sapling	5 - 20	20 - 35	35 - 40	40 - 45	45 - 50	50 - 55
0	1200	150	141	94	23	14	0	0
5	48	439.5	159.6	84.26	31.42	15.24	4.33	0
10	1.92	685.6	156.9	78.88	33.77	17.86	4.12	0
15	0.08	1070	152.9	75.53	33.21	20.03	4.88	0
20	0	1669	147.3	73.89	31.53	21.27	5.46	0
25	0	2603	140.3	73.34	29.61	21.67	5.78	0
30	0	4061	132.2	73.38	27.83	21.47	5.88	0
35	0	6334	123.5	73.58	26.35	20.92	5.82	0
40	0	9882	114.5	73.63	25.19	20.21	5.66	0
45	0	15415	105.4	73.3	24.34	19.47	5.47	0
50	0	24048	96.55	72.47	23.74	18.78	5.27	0
55	0	37515	88.01	70.39	23.06	18.18	5.08	0
60	0	58523	79.91	68.65	22.67	17.62	4.92	0

TABLE VI (CONTINUE)
SIMULATION FOR SPECIES GROUP 1

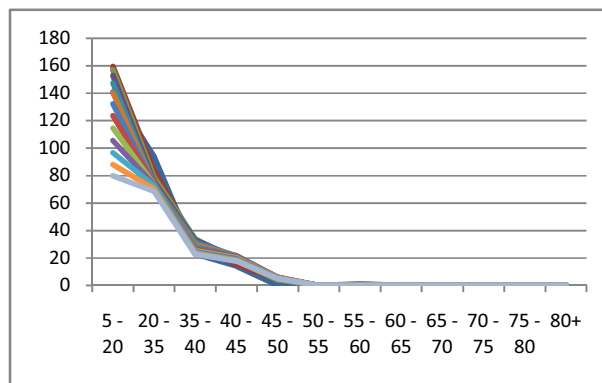| Year	55 - 60	60 - 65	65 - 70	70 - 75	75 - 80	80+	Total
0	1	0	0	0	0	0	273
5	0.61	0.33	0	0	0	0	296
10	0.38	0.19	0	0	0	0	292
15	0.23	0.12	0	0	0	0	287
20	0.14	0.07	0	0	0	0	280
25	0.09	0.04	0	0	0	0	271
30	0.05	0.03	0	0	0	0	261
35	0.03	0.02	0	0	0	0	250
40	0.02	0.01	0	0	0	0	239
45	0.01	0.01	0	0	0	0	228
50	0.01	0	0	0	0	0	217
55	0	0	0	0	0	0	205
60	0	0	0	0	0	0	194

Fig. 2(a) Tree growth simulation curves for species group 1
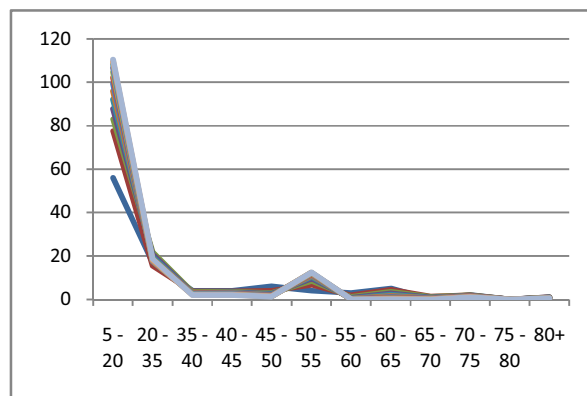

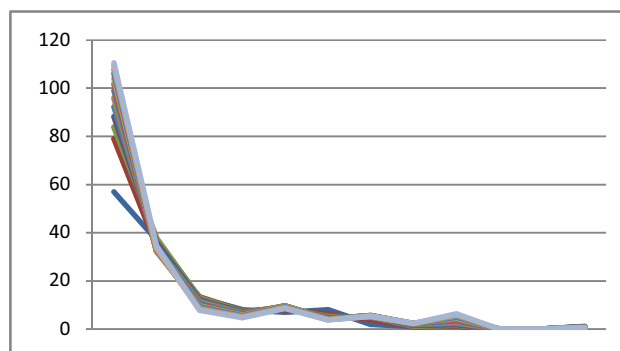Fig. 3(b) Tree growth simulation curves for species group 2

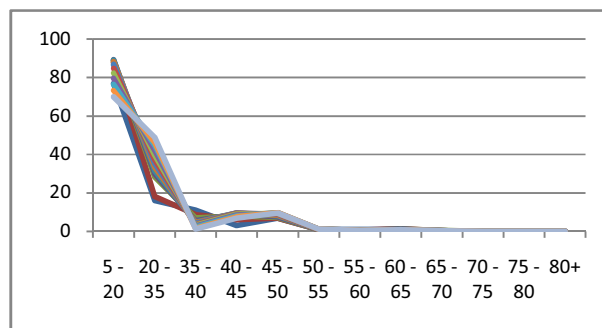Fig. 3(c) Tree growth simulation curves for species group 3

Fig. 3(d) Tree growth simulation curves for species group 4

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V.   Conclusion And Recommendation

Four species groups from Koh Kong province, Cambodia have been successfully produced by using cluster analysis based on their three diameter growth throughout thirteen years of measurement. The diameter interval class, annual diameter increment, mortality rate and recruitment rate were produced and calculated by species groups. These parameters were used to simulate the growth of the tree according to their groups and diameter interval class using some mathematical equations. The simulation was magnificently done in 5-year interval throughout 60 years using Microsoft excel. The result suggests that the number of trees increased at year-60 except for species group 1; however, species group 1 produces higher number of trees with diameter class of 35 cm to 50 cm. There are very few trees grow more than 70 cm of the diameter. The simulation system developed in the present work can be considered a useful tool to simulate the growth of the trees particularly in Cambodia.   It is recommended that the simulation system can be improved by performing it in presentable manner using one of modern computer languages.

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