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by Tri Mulyaningsih

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Sustainability Strategy of Agarwood-Production Trees in Lombok Island using Harvesting Matrix

Sustainability Strategy of Agarwood-Production Trees in Lombok Island using Harvesting Matrix

M U Romdhini[1*], N Fitriyani[1], A Kurnia[1], I K A Baskara[1], M Ito[2], I Yamada[3], S Hadi[4] and T Mulyaningsih[5]

[1]Mathematics Department, Universitas Mataram, Mataram, Indonesia
[2]Graduate School of Pharmaceutical Sciences, Kyoto University, Japan
[3]Center for Southeast Asian Studies, Kyoto University, Japan
[4]Chemistry Department, Universitas Mataram, Mataram, Indonesia
[5]Biology Department, Universitas Mataram, Mataram, Indonesia

*Corresponding author's email: mamika_ur@yahoo.com

Abstract. Eaglewood (*Gyrinops verstiigee*) is one example of a commercially valuable aromatic plant in the form of agarwood. The high selling value of agarwood encourages people to use it. The distribution area of Agarwood-producing trees is found in several regions in Indonesia. One of agarwood producers has been widely exploited in West Nusa Tenggara Province. The problem is the number of population and the quality of agarwood production which is declining due to exploitation carried out continuously and excessively without calculations and improper harvesting techniques. Therefore, a forest management model that cares for sustainability, called a sustainable harvesting model, could be used. This research used harvesting matrix to build this model. This model considers the initial configuration of the forest to be the same as the final configuration of the forest, so that the harvesting could be done continuously without damaging the forest configuration. The location of data collection was conducted in several areas, such as Orong Puncak, Lembah Sari, Orong Selatan, Kekait, Sepakek, East Lombok, and Kerujuk. The data obtained were divided into 5 intervals based on the diameter of the eaglewood tree. The research found that the number of trees that could be harvested on one harvesting period at each interval of trees diameter, i.e. 0 tree in 0-10 cm interval; 388 trees in 10-20 cm interval; 270 trees in 20-30 cm interval; 17 trees in 30-40 cm interval; and 3 trees in 40-50 cm interval. Harvesting matrix could be used to help the government in order to build a strategy for the sustainability of eaglewood trees in Lombok Island.
Keywords: eaglewood, forest configuration, forest management, tree diameter

1. Introduction

Eaglewood is a commercially valuable aromatic plant in the form of agarwood (sapwood and kemedangan). Agarwood began to be known to the Indonesian people around 1200, which was only obtained from the collection of natural forest products by utilizing natural dead trees in the form of clumps, debris, and cinders, which were the waste of the cleaning process. As one of the commodities of forest products, agarwood is widely used for various purposes, such as perfume and traditional medicine. The form of trade in agarwood varies from chunks of wood, powder (ash), and agarwood oil. Agarwood is widely exported to Arab countries, Singapore, and China [1].

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One of the producers of agarwood has been widely exploited in the area of West Nusa Tenggara and East Nusa Tenggara. Nowadays the population number and quality of agarwood-production decreases due to exploitation carried out continuously and excessively without calculations and improper harvesting techniques. Therefore, today the agarwood trees are increasingly scarce and the location for finding agarwood is getting farther into the forest, also the time taken for making taking is getting longer [2].

Therefore, a forest management model concerned with forest sustainability is needed. This model is called a sustainable harvesting model. This model is very suitable to be applied in forest management related to forest harvesting, because the sustainable harvesting model stipulates that the initial configuration of the forest must be the same as the final configuration of the forest, so that harvesting can be carried out continuously without changing the forest configuration [3].

2. Literature Review

According to [3], the compilation of sustainable harvesting models is based on several assumptions, i.e. not counting trees that die between harvest times and each plant planted survives and grows until it can be harvested. By this way, the number of trees in the forest will always be the same. Consider Figure 1 below.

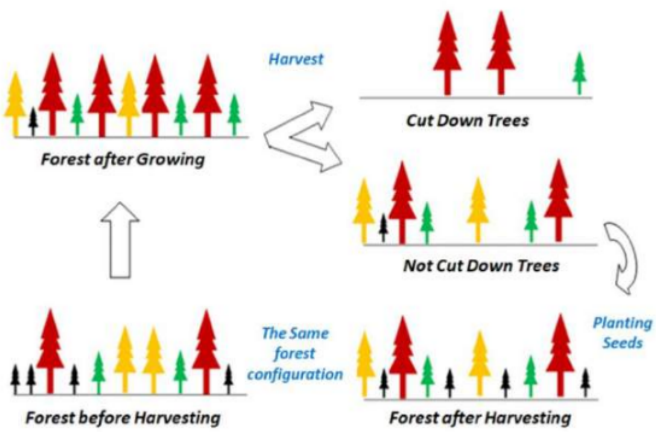

Figure 1. Sustainable Forest Harvest Cycle.

From Figure 1, it can be seen that the forest before harvest (the forest at the beginning of growth) has the same forest configuration as the forest after harvest (forest at the end of growth). The forest configuration is the number of trees in each diameter class that can be represented by vectors. Consider Table 1 below to see the configuration of forest before harvest (forest at the beginning of growth).

Table 1. Interval Class Description Based on Class and Diameter of the Eaglewood Tree.

Class	Interval Diameter
1	$[0, h_1)$
2	$[h_1, h_2)$
3	$[h_2, h_3)$

Class	Interval Diameter
$\vdots$	$\vdots$
$n-1$	$[h_{n-2}, h_{n-1})$
n	$[h_{n-1}, \infty)$

Let $x_1 \, (i=1,2,\cdots,n)$ be the number of trees in the first – class before a period of growth, then a column vector of $\boldsymbol{x}$ can be formed, called a non-harvest vector.

$$\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}$$

x_1 indicates the number of trees in the first – class at the beginning of the growth period, x_2 indicates the number of trees in the second – class at the beginning of the growth period, and x_n indicates the number of trees in the nth – class at the beginning of the growth period.

To construct a sustainable harvesting policy, after every harvest, the forest is returned to a fixed configuration, determined by a non-harvest vector $\boldsymbol{x}$. Since the number of trees in the forest is fixed, the following equation can be determined.

$$x_1 + x_2 + \cdots + x_n = s \tag{1}$$

When reviewed from the growth of the forest between harvest times, a tree in the first – class can grow and increase to a higher class or remain in the same class due to various natural factors. As a result, g_i and $1-g_i$, can be defined as the growth parameters. For $i=1,2,\cdots,n-1$, g_i is the fraction of the first – class trees that grow to $(i+1)th$ – class in one period of growth, and $1-g_i$ is fraction of the first – class trees that remain in the first – class in one period of growth.

With *n – 1* growth parameters, a growth matrix of *n x n* can be formed as follows.

$$\mathbf{G} = \begin{bmatrix} 1-g_1 & 0 & 0 & \cdots & 0 & 0 \\ g_1 & 1-g_2 & 0 & \cdots & 0 & 0 \\ 0 & g_2 & 1-g_3 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & 1-g_{n-1} & 0 \\ 0 & 0 & 0 & \cdots & g_{n-1} & 1 \end{bmatrix} \tag{2}$$

Since the elements of vector x are the number of trees in n classes before a growth period, the input of the vector $\mathbf{Gx}$ can be written as follows.

$$\mathbf{Gx} = \begin{bmatrix} (1-g_1)x_1 \\ g_1x_1 + (1-g_2)x_2 \\ g_2x_2 + (1-g_3)x_3 \\ \vdots \\ g_{n-2}x_{n-2} + (1-g_{n-1})x_{n-1} \\ g_{n-1}x_{n-1} + x_n \end{bmatrix} \quad (3)$$

Information:
$\mathbf{Gx} =$ the number of trees in n classes after a period of growth;
$(1-g_1)x_1 =$ the number of trees in the first – class at the end of the growth period;
$g_1x_1 + (1-g_2)x_2 =$ the number of trees in the second – class at the end of the growth period;
$g_2x_2 + (1-g_3)x_3 =$ the number of trees in the third – class at the end of the growth period; and
$g_{n-1}x_{n-1} + x_n =$ the number of trees in the nth – class at the end of the growth period.

During the harvesting period, for example, $y_i\,(i = 1,2,\cdots,n)$ number of trees taken from the ith – class. So that a vector $\boldsymbol{y}$ can be formed as a harvest vector.

$$\mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}$$

Information:
$y_1 =$ the number of trees harvested in the first – class after the end of the growth period;
$y_2 =$ the number of trees harvested in the second – class after the end of the growth period; and
$y_n =$ the number of trees harvested in the nth – class after the end of the growth period.

So, there is a total number of $y_1 + y_2 + \cdots + y_n$ trees cut down each harvest period. This amount of number is also the total number of trees added to the first – class (new seedlings) after each harvest period of time. For example,

$$\mathbf{R} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & 0 \end{bmatrix} \quad (4)$$

$\boldsymbol{R}$ is defined as a replacement matrix $n \times n$. Then obtained a column vector,

$$\mathbf{Ry} = \begin{bmatrix} y_1 + y_2 + \cdots + y_n \\ 0 \\ \vdots \\ 0 \end{bmatrix} \quad (5)$$

with $\mathbf{Ry}$ determines the configuration of trees planted after each harvest period.

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From the previous result on forest management policies, we can conclude the equation that characterizes a sustainable harvesting policy, as follows:

$$\begin{bmatrix} configuration \\ at\ the\ end \\ of\ the\ growth\ period \end{bmatrix} - [harvest] + \begin{bmatrix} subtitute \\ for\ new\ seedlings \end{bmatrix} = \begin{bmatrix} configuration \\ at\ the\ beginning \\ of\ the\ growth\ period \end{bmatrix}$$

Mathematically written as:

$$\mathbf{Gx} - \mathbf{y} + \mathbf{Ry} = \mathbf{x} \tag{6}$$

Equation (6) can be described as the equation below:

$$(\mathbf{I} - \mathbf{R})\mathbf{y} = (\mathbf{G} - \mathbf{I})\mathbf{x} \tag{7}$$

More fully, equation (7) can be written as follows [3]:

$$\begin{bmatrix} 0 & -1 & -1 & \cdots & -1 & -1 \\ 0 & 1 & 0 & \cdots & 0 & 0 \\ 0 & 0 & 1 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & 1 & 0 \\ 0 & 0 & 0 & \cdots & 0 & 1 \end{bmatrix} \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ \vdots \\ y_{n-1} \\ y_n \end{bmatrix} = \begin{bmatrix} -g_1 & 0 & 0 & \cdots & 0 & 0 \\ g_1 & -g_2 & 0 & \cdots & 0 & 0 \\ 0 & g_2 & -g_3 & \cdots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \cdots & -g_{n-1} & 0 \\ 0 & 0 & 0 & \cdots & g_{n-1} & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ \vdots \\ x_{n-1} \\ x_n \end{bmatrix} \tag{8}$$

Since the trees in the first – class are seedlings that have no selling value or cannot be harvested, it is determined that:

$$y_1 = 0 \tag{9}$$

So, from equation (8), the following equation is obtained:

$$\begin{aligned} & y_2 + y_3 + \cdots + y_n = g_1 x_1 \\ & y_2 = g_1 x_1 - g_2 x_2 \\ & y_3 = g_2 x_2 - g_3 x_3 \\ & \vdots \\ & y_{n-1} = g_{n-2} x_{n-2} - g_{n-1} x_{n-1} \\ & y_n = g_{n-1} - x_{n-1} \end{aligned} \tag{10}$$

From equation (9) and equation (10), the following equation is obtained:

$$\begin{aligned} & y_1 = 0 \\ & y_2 = g_1 x_1 - g_2 x_2 \\ & y_3 = g_2 x_2 - g_3 x_3 \\ & \vdots \\ & y_{n-1} = g_{n-2} x_{n-2} - g_{n-1} x_{n-1} \\ & y_n = g_{n-1} - x_{n-1} \end{aligned} \tag{11}$$

Since $y_i \geq 0$, for $i = 1,2,\ldots,n$, then equation (11) requires that [3]:

$$g_1 x_1 \geq g_2 x_2 \geq \cdots \geq g_{n-1} x_{n-1} \geq 0 \tag{12}$$

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3. Research Methodology

This study aimed to find out: (a) sustainable harvesting models of eaglewood trees on Lombok Island, and (b) the number of trees that can be harvested at each interval of tree diameters in one harvest period from sustainable harvesting models obtained. This research was a study with literature studies, by looking for references on theories that were relevant to the case or problem raised, which were used as the basis for conducting research. The data used in this study were primary data and secondary data. Secondary data was used as preliminary data on the growth of agarwood-production trees on Lombok Island, obtained from inventory data on potential production forests in Mount Rinjani Forest Area in 2013 [4]. The primary data was conducted by the research team, which contained data on the growth of agarwood-production trees on Lombok Island. The steps used in this study were: (a) literature study; (b) data collection; (c) interval distribution based on tree diameter; (d) model application; and (e) conclusions.

4. Results and Discussion

Table 2 shows data on the number of trees in each of the 5 classes of tree diameter intervals based on the data obtained.

Table 2. Description of Agarwood-Production Tree Interval Classes on Lombok Island.

Class	**Tree Diameter Interval** (cm)	**Number of Trees in the Beginning** (x_i)	**Number of Trees that are Remains in the *i*th-class** (x_i^i)	**Number of Trees that Move to *(i+1)*th-class** (x_i^{i+1})
1	[0-10)	3843	3165	678
2	[10-20)	1099	809	290
3	[20-30)	53	33	20
4	[30-40)	12	9	3
5	[40-50)	6		

Based on Table 2, a column vector $\boldsymbol{x}$ can be formed as follows, by substituting each value of x_1, x_2, x_3, x_4, and x_5 from Table 2.

$$\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix} = \begin{bmatrix} 3843 \\ 1099 \\ 53 \\ 12 \\ 6 \end{bmatrix}$$

Information:

x_1 = number of agarwood-production trees in the 1st – class 1 at the beginning of the growth period;
x_2 = number of agarwood-production trees in the 2nd – class 1 at the beginning of the growth period;
x_3 = number of agarwood-production trees in the 3rd – class 1 at the beginning of the growth period;
x_4 = number of agarwood-production trees in the 4th – class 1 at the beginning of the growth period; and
x_5 = number of agarwood-production trees in the 5th – class 1 at the beginning of the growth period.

Furthermore, we can set up a *5 x 5* growth matrix as follows:

$$\mathbf{G}=\begin{bmatrix} 1-g_1 & 0 & 0 & 0 & 0 \\ g_1 & 1-g_2 & 0 & 0 & 0 \\ 0 & g_2 & 1-g_3 & 0 & 0 \\ 0 & 0 & g_3 & 1-g_4 & 0 \\ 0 & 0 & 0 & g_4 & 1 \end{bmatrix}$$

Then the following fraction values are obtained:

$$g_1=\frac{678}{3843}=0{,}1764\ ; \qquad 1-g_1=\frac{3165}{3843}=0{,}8236$$

$$g_2=\frac{290}{1099}=0{,}2693\ ; \qquad 1-g_2=\frac{809}{1099}=0{,}7361$$

$$g_3=\frac{20}{53}=0{,}3774\ ; \qquad 1-g_3=\frac{33}{53}=0{,}6226$$

$$g_4=\frac{3}{12}=0{,}25\ ; \qquad 1-g_4=\frac{9}{12}=0{,}75$$

By substituting the fraction values into the matrix ***G***, it is obtained:

$$\mathbf{G}=\begin{bmatrix} 0{,}8236 & 0 & 0 & 0 & 0 \\ 0{,}1764 & 0{,}7361 & 0 & 0 & 0 \\ 0 & 0{,}2639 & 0{,}6226 & 0 & 0 \\ 0 & 0 & 0{,}3774 & 0{,}75 & 0 \\ 0 & 0 & 0 & 0{,}25 & 1 \end{bmatrix}$$

Vector ***Gx*** is defined as the number of agarwood-production trees after one period of growth. So, we obtain:

$$\mathbf{Gx}=\begin{bmatrix} (1-g_1)x_1 \\ g_1x_1+(1-g_2)x_2 \\ g_2x_2+(1-g_3)x_3 \\ g_3x_3+(1-g_4)x_4 \\ g_4x_4+x_5 \end{bmatrix}=\begin{bmatrix} 3165 \\ 1487 \\ 323 \\ 29 \\ 9 \end{bmatrix}$$

Vector ***y*** as the harvest vector can be written as follows:

$$\mathbf{y}=\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{bmatrix}$$

R is defined as a *5 x 5* replacement matrix.

$$\boldsymbol{R} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

So, the $\boldsymbol{Ry}$ vector becomes,

$$\boldsymbol{Ry} = \begin{bmatrix} y_1 + \ y_2 + \ y_3 + \ y_4 + \ y_5 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$\boldsymbol{Ry}$ determines the configuration of trees planted after being ready for harvest. Based on equation (11), we obtain:

$y_1 = 0$;

$y_2 = (0{,}1764 \times 3843) - (0{,}2639 \times 1099) = 388$;

$y_3 = (0{,}2639 \times 1099) - (0{,}3774 \times 53) = 270$;

$y_4 = (0{,}3774 \times 53) - (0{,}25 \times 12) = 17$; and

$y_5 = (0{,}25 \times 12) = 3$.

Suitability of the continuous harvesting model that sets the initial configuration must be the same as the final configuration, can be known through the application of equation (6), with the following details.

$$\mathbf{Gx} - \mathbf{y} + \mathbf{Ry} \;=\; \mathbf{x}$$

$$\begin{bmatrix} (1-g_1)x_1 \\ g_1 - x_1 + (1-g_2)x_2 \\ g_2x_2 + (1-g_3)x_3 \\ g_3x_3 + (1-g_4)x_4 \\ g_4x_4 + x_5 \end{bmatrix} - \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{bmatrix} + \begin{bmatrix} y_1 + \ y_2 + \ y_3 + \ y_4 \ y_5 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix}$$

$$\begin{bmatrix} 3165 \\ 1487 \\ 323 \\ 29 \\ 9 \end{bmatrix} - \begin{bmatrix} 0 \\ 388 \\ 270 \\ 17 \\ 3 \end{bmatrix} + \begin{bmatrix} 0 + \ 388 + \ 270 + \ 17 \ 3 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} 3843 \\ 1099 \\ 53 \\ 12 \\ 6 \end{bmatrix}$$

$$\begin{bmatrix} 3843 \\ 1099 \\ 53 \\ 12 \\ 6 \end{bmatrix} = \begin{bmatrix} 3843 \\ 1099 \\ 53 \\ 12 \\ 6 \end{bmatrix}$$

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The results prove that the initial configuration of the forest is the same as the final configuration of the forest.

Thus, the total agarwood-production trees on Lombok Island which can be harvested in one harvest period are 0 tree in 0-10 cm interval; 388 trees in 10-20 cm interval; 270 trees in 20-30 cm interval; 17 trees in 30-40 cm interval; and 3 trees in 40-50 cm interval.

5. Conclusion

Harvesting matrix obtained could be used to help the government in order to build a strategy for the sustainability of agarwood-production trees in Lombok Island.

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