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Table of contents

Volume 1374

2019

[◀ Previous issue](#) [Next issue ▶](#)

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Preface

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011001

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Peer review statement

[+](#) View abstract [View article](#) [PDF](#)

011002

Papers

Biological Physics

OPEN ACCESS

Separation of Flavonoids in The Extract *Polyalthia longifolia* (Sonn.) Thw. Leaves from Indonesia and The Philippines

D S Nahari, S Prasetyawan, M A G Beltran and A Aulianri'am

[+](#) View abstract [View article](#) [PDF](#)

012001

OPEN ACCESS

012002

The Effect of Snake Fruit (*Salacca edulis Reinw.*) Seed Extract On Body Weight In Female Rats Model with Iron Deficiency Anemia

D Melati, D G Tamtomo and D Indarto

➤ View abstract [View article](#) [PDF](#)

OPEN ACCESS 012003

Effects Of 25%, 37.5% and 50% *Musa Acuminata* Extract as a Denture Cleanser on the Flexural Strength and Surface Roughness of Acrylic Resin

D Puspitasari, A Setiawan, D F Annisa, S R Pramitha and M L Apriasari

➤ View abstract [View article](#) [PDF](#)

OPEN ACCESS 012004

Effect of Active Compound of Pasak Bumi Root (*Euricoma longifolia*, Jack) as an inhibitor of CDK2 methylation: *In Silico* Study

E Y Rahman, M Ali, B B Purnomo, N Kania, D H Utomo and P W Nurikhwan

➤ View abstract [View article](#) [PDF](#)

OPEN ACCESS 012005

Production and Optimization of Lipase by *Aspergillus niger* using Coconut Pulp Waste in Solid State Fermentation

E Suyanto, E S Soetarto and M N Cahyanto

➤ View abstract [View article](#) [PDF](#)

OPEN ACCESS 012006

Antioxidant and Anti-Inflammatory activity of Chlorogenic Acid on Lead-Induced Fibroblast Cells

E Girsang, I N E Lister, C N Ginting, S L Nasution, S Suhartina, U Z Munshy, R Rizal and W Widowati

➤ View abstract [View article](#) [PDF](#)

OPEN ACCESS 012007

Biosorption of Synthetic Dye from Batik Wastewater Using *Trichoderma viride* Immobilized on Ca-Alginate

G Rahmaniah, C Mahdi and A Safitri

➤ View abstract [View article](#) [PDF](#)

OPEN ACCESS 012008

Detection and Analysis of Delayed-Ripening Genes in the Growth of Strawberries (*Fragaria × ananassa*) Treated 1-Naphthaleneacetic Acid

G R Arisya, N T A Maulina, M F Afrir, R S Kasiamdari and A Widiastruti

➤ View abstract [View article](#) [PDF](#)

OPEN ACCESS 012009

Hepatoprotective effect of Eugenol on Acetaminophen-Induced Hepatotoxicity in HepG2 cells

I N E Lister, C N Ginting, E Girsang, A Amansyah, L Chiuman, N L W E Yanti, R Rizal and W Widowati

➤ View abstract [View article](#) [PDF](#)

OPEN ACCESS 012010

Martapura river water leads to testes alteration in rats

I Yuliana, H Khatimah, L Rosida, N S Skripsiana and E Suhartono

➤ View abstract  View article  PDF

OPEN ACCESS 012011

DNA barcoding as a method for species identification: case study in *Ahaetulla* snake

L I N Indahsari, F Fatchiyah and N Kurniawan

➤ View abstract  View article  PDF

OPEN ACCESS 012012

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

M U Romdhini, N Fitriyani, A Kurnia, I K A Baskara, M Ito, Yamada, S Hadi and T Mulyaningstih

➤ View abstract  View article  PDF

OPEN ACCESS 012013

Snake Fruit Seeds Flour-Fortified Jelly for Supplementary Feeding in Adolescent Girls with Anemia

M A Nugraheni, D Indarto and E P Pamungkasari

➤ View abstract  View article  PDF

OPEN ACCESS 012014

Kelakai Extract Protects Skin From UV-Induced Oxidative Damage

M Mashuri, L D M Sihombing, S Alfaqihah, E Edyson and E Suhartono

➤ View abstract  View article  PDF

OPEN ACCESS 012015

The effect of kaffir lime (*Citrus hystrix* DC) essential oil on bioplastic derived from cassava peel waste

M Masruri, A Z Azhar, I Rosyada and A Febrianto

➤ View abstract  View article  PDF

OPEN ACCESS 012016

Antioxidant activity of vacuum column chromatography fractions of ethanol extract of sarang banua (*Clerodennum fragrans* vent willd) leaves

M Simorangkir, B Nainggolan and S Silaban

➤ View abstract  View article  PDF

OPEN ACCESS 012017

The Difference of Amino Acid Profiling From Two Morphological Purple Sweet Potatoes From Kawi Mountain Cultivars, East Java, Indonesia

N Kurnianingsih, R Ratnawati, F Fatchiyah, W Barlianto, M M Ali, A Saffiri and E Suyanto

➤ View abstract  View article  PDF

OPEN ACCESS 012018

Phytoconstituents Investigation on the Ethanolic Extract of *Azadirachta indica* var. Indonesian and Philippines

R Raissa, A Safitri, M A G Beltran and A Aulannilam

[+](#) View abstract
 [View article](#)
[PDF](#)

OPEN ACCESS 012019

Growth of Sunu Grouper (*Plectropomus leopardus*) Larvae That Given Rotivera (*Bachionus rotundiformus*) Enriched with Taurine and Glutamine

R Rostika, Iskandar, T Herawati, I Bangkit, G Banthani and L P Dewanti

[+](#) View abstract
 [View article](#)
[PDF](#)

OPEN ACCESS 012020

Antioxidant potential ethanolic extract of *Glycine max*(L.) Merr. Var. Detam and daidzein

S Prahasuti, M Hidayat, S T Hasianna, W Widowati, A Amalia, D T Yusepany, R Rizal and H S W Kusuma

[+](#) View abstract
 [View article](#)
[PDF](#)

OPEN ACCESS 012021

The antibacterial activities of bacteriocin *Pediococcus acidilactici* of breast milk isolate to against methicillin-resistant *Staphylococcus aureus*

S D Lestari, A L O Sadiq, W A Safitri, S S Dewi and M E Prastiyanto

[+](#) View abstract
 [View article](#)
[PDF](#)

OPEN ACCESS 012022

Biocellulose isolated from the waste of pinecone flower (*Pinus merkusii* Jungh Et De Vriese)

S E Lusiana, M M Aisyah, U Z 'Uyunin, Z D Nashih, A Srihardyastutie, M F Rahman and M Masruri

[+](#) View abstract
 [View article](#)
[PDF](#)

OPEN ACCESS 012023

Cellulose nanocrystal (CNC) produced from the sulphuric acid hydrolysis of the pine cone flower waste (*Pinus merkusii* Jungh Et De Vriese)

S E Lusiana, A Srihardyastutie and M Masruri

[+](#) View abstract
 [View article](#)
[PDF](#)

OPEN ACCESS 012024

Comparative Analysis of Wharton's Jelly Mesenchymal Stem Cell (WJ-MSCs) Isolated Using Explant and Enzymatic Methods

W Widowati, R F Gunanegara, R Rizal, W S Widodo, A Amalia, S H B Wibowo, K Handono, M Marlina, I N E Lister and L Chiuman

[+](#) View abstract
 [View article](#)
[PDF](#)

OPEN ACCESS 012025

Genotype and Serotype Identification of Hepatitis B Virus in Chronic Hepatitis B Patients Treated with Telbivudine

Y Purnamasari, Tien, Arimaswati, A N K Syarifin, A Ali and N Massi

[+](#) View abstract
 [View article](#)
[PDF](#)

Medical Physics

OPEN ACCESS 012026

Molecular Docking Study from Lunacridine, Scopoletin and Skimmianine as Antidiabetes through α -Glucosidase Inhibitor

Adriani, Noorhamdani, S Winarsih and T Ardyati

[+](#) View abstract [View article](#) [PDF](#)

OPEN ACCESS 012027

Preparation of Nanoparticles from *Curcuma longa* L. and *Cosmos caudatus* Extracts

A S Putri, T D Octavianity, N T Wahyudi and A Saifiri

[+](#) View abstract [View article](#) [PDF](#)

OPEN ACCESS 012028

The Effect of Topical Toman Fish (*Channa micropeltes*) Extract on Macrophages and Lymphocytes in Diabetes Mellitus Wound Healing

A N Carabelly, I W A K Firdaus, P C Nurmardina, D A Putri and M L Aprasari

[+](#) View abstract [View article](#) [PDF](#)

OPEN ACCESS 012029

The preventive effect of activated charcoal on HDL levels and aorta histopathological profiles in hypercholesterol rat models

A Roosdiana, D Vidiastuti and H Herenda

[+](#) View abstract [View article](#) [PDF](#)

OPEN ACCESS 012030

Anti-diabetic properties of root extracts of *Ruellia tuberosa* L: effects on serum enzyme activity

A Saifiri, A Roosdiana, N Arrochmah and S S Nur'Adya

[+](#) View abstract [View article](#) [PDF](#)

OPEN ACCESS 012031

Total and Differential Cells of Leukocyte Mice (*Mus musculus*) On Evaluation In Vivo Anticancer Extracts Ethanol Marine Sponges *Aaptos suberitoides*

A P D Nurhayati, R Pratiwi and Soekardiman

[+](#) View abstract [View article](#) [PDF](#)

OPEN ACCESS 012032

The Effects of Isolate of Goat Casein Yoghurt Milk to MDA Level and Gastric Histopathology of Rats Exposed to 2,3,7,8-Tetrachlorodibenzo-P-Dioxin (TCDD)

C Mahdi, A E P Haskito and M H Robbie

[+](#) View abstract [View article](#) [PDF](#)

OPEN ACCESS 012033

Anti-inflammatory Activity of Quercitrin on Hypoxia-induced EA.hy926

C N Ginting, I N E Lister, E Girsang, M S Mutia, Y E P Lubis, A Amalia, R Rizal and W Widowati

- [+](#) View abstract [View article](#) [PDF](#)
- OPEN ACCESS**
- Interaction of cadmium-cysteine binding and oxidation of protein causes of blood thrombosis
- D Marisa, I Afianie, N Muthmainah and E Suhartono
- [+](#) View abstract [View article](#) [PDF](#)
- 012034
- OPEN ACCESS**
- Changes of Biologic Marker in Neonatal Sepsis: Is it significance?
- D I N Pratiwi, P W Nurikhwan and W R Devi
- [+](#) View abstract [View article](#) [PDF](#)
- 012035
- OPEN ACCESS**
- Effect of DHA Supplementation on The MDA and SOD Levels in Protein Malnourished Rats
- D D Sanyoto, A Asnawati and T Triawanti
- [+](#) View abstract [View article](#) [PDF](#)
- 012036
- OPEN ACCESS**
- The Role of Prophylactic Antibiotics on ANC Value and Fever Duration in Cancer Patients with Post-Chemotherapy Neutropenia Fever
- E P Yunita, G J R Subagiyo and S O Wardhani
- [+](#) View abstract [View article](#) [PDF](#)
- 012037
- OPEN ACCESS**
- Immunological Responses in Female Rats Model with Anemia Treated with Snake Fruit Seed Flour Extract
- I K Ristanti, D G Tamtomo and D Indarto
- [+](#) View abstract [View article](#) [PDF](#)
- 012038
- OPEN ACCESS**
- Effect of fat supplementation containing high palmitic acid enriched with lecithin on quail performances
- I Syarif, W Hermana and Y Retnani
- [+](#) View abstract [View article](#) [PDF](#)
- 012039
- OPEN ACCESS**
- Dihydroeponeymycin inhibits ubiquitin proteasome system of *Plasmodium falciparum in silico*
- K Mardhiyah, M H Arif, L E Fitri, S Winarsih, D Chandradikusuma and T Nurseta
- [+](#) View abstract [View article](#) [PDF](#)
- 012040
- OPEN ACCESS**
- In Silico: Y-Oryzanol as Anti-inflammatory During Folliculogenesis in Rattus Novergicus Exposed to Pyrethroid Aerosol
- L Lisnawati, M I E Santoso, S Poeranto and A T Endharti
- 012041

- [+](#) View abstract [View article](#) [PDF](#)
- OPEN ACCESS**
 The Effect of High Fat High Fructose Diet (Modification of AIN-93M) on Nuclear Factor Kappa Beta Expression in the Liver Tissue of Male Sprague Dawley Rats
 M M S Engel, I Kusumastuty, K W Anita and D Handayani
[+](#) View abstract [View article](#) [PDF](#)
- 012042
- OPEN ACCESS**
 The Improvement of INS Gene Sequences on Rat Model of Type 1 Diabetes in Goat Milk Casein Protein Treatment, but not in Gibbendamide
 M Mulyati, E Y Mujizah and F Fatchiyah
[+](#) View abstract [View article](#) [PDF](#)
- 012043
- OPEN ACCESS**
 Systemic lupus erythematosus: PKCA is an inhibition pathway for mTOR by the active ingredient of green tea
 H Mawardi, J Nugraha, D A Purwanto and J Soeroso
[+](#) View abstract [View article](#) [PDF](#)
- 012044
- OPEN ACCESS**
 FSH Receptor Gene Polymorphism in Indonesian Women with Polycystic Ovarian Syndrome (PCOS)
 R Panghiyangan, M Kurniati, P Soeharso, A Andrijono, D A Suryandari and B Wiweko
[+](#) View abstract [View article](#) [PDF](#)
- 012045
- OPEN ACCESS**
 Genomic Profile of rIR and rRR in Type 2 Diabetes Mellitus Rat Model toward Effect of Goat Milk CSN1S2 Protein
 S H Tambunan, H N Meldinna, R N Rohmah and F Fatchiyah
[+](#) View abstract [View article](#) [PDF](#)
- 012046
- OPEN ACCESS**
 Construction and Optimization of Prethrombin-2 Human Genes in *E. coli* for the Production of Active Thrombin
 S Silaban, S Gaffar, M Simorangkir, I P Maksum and T Subroto
[+](#) View abstract [View article](#) [PDF](#)
- 012047
- OPEN ACCESS**
 Protein-based virtual screening: SIRT-1 as modulator maturation of circulating endothelial progenitor cells
 T A Wihastuti, W Nurwidyaningtyas, C T Tjahjono and T Heriansyah
[+](#) View abstract [View article](#) [PDF](#)
- 012048
- OPEN ACCESS**
 Identification and molecular docking analysis alkaloids *Polyalthia longifolia* leaves from Indonesia and the Philippines as anti-inflammatory
 T Z Anita, C Mahdi, M A G Beltran and A Aulannitam
- 012049

- [+](#) View abstract [View article](#) [PDF](#) 012050
OPEN ACCESS
 Swallow nest extract can be able to prevent nephropathy diabetic of the white rats streptozotocin-induced
 T Triawanti, F D Alexandra, A Frerthermy and S Mahmud
[+](#) View abstract [View article](#) [PDF](#)
- OPEN ACCESS** 012051
 Effects of Probiotic Treatment on Histopathology of Koi Carp (*Cyprinus carpio*) Infected by *Myxobolus* sp.
 U Yanuhar, N S Junirahma, K Susilowati, N R Caesar and M Musa
[+](#) View abstract [View article](#) [PDF](#)
- OPEN ACCESS** 012052
 Anti-Inflammation Assay of Black Soybean Extract and Its Compounds on Lipopolysaccharide-Induced RAW 264.7 Cell
 W Widowati, S Prahastuti, N L W Ekayanti, U Z Munshy, H S W Kusuma, S H B Wibowo, A Amalia, W S Widodo and R Rizal
[+](#) View abstract [View article](#) [PDF](#)
- OPEN ACCESS** 012053
 The decrease in bacterialcount in adult chronic rhinosinusitis patients after nasal irrigation therapy with NaCl 0,9% Solution
 N Qamariah, N Muthaimah and R B B Tanjoto
[+](#) View abstract [View article](#) [PDF](#)
- OPEN ACCESS** 012054
 Molecular docking of the active compound *Garcinia mangostana* on the RANKL/RANK/OPG system
 B Setiawan, E Suhartono, S Kaldah, I Z Akbar and Z Noor
[+](#) View abstract [View article](#) [PDF](#)
- OPEN ACCESS** 012055
 Urological cancer: molecular docking of the active compound *Scurula atropurpurea* against nuclear factor erythroid2-related factor2 (Nrf2)
 H Prasetya, F R P Dewi and B Setiawan
[+](#) View abstract [View article](#) [PDF](#)
- OPEN ACCESS** 012056
 Effect Of Coal Dust Exposure To Serum Interleukin 6 (IL6) And Vascular Endothelial Growth Factor (VEGF) Level As Preeclampsia Induction In Pregnant Rattus Novergicus
 S Wasiliah, F Rachman, D Rosadi, A O Pureri, N Laily, F Yulidasari, L Angraeni, B Setiawan and M S Noor
[+](#) View abstract [View article](#) [PDF](#)
- OPEN ACCESS** 012057
 Estimation of leaf antioxidant activity using image processing
 E Suhartono, B Setiawan, P B Santosa, R Idroes and M S Indrawan

- + View abstract  View article  PDF
- + View abstract  View article  PDF

012058

OPEN ACCESS
Abdominal Circumference, Body Fat Percent, and VO_2 Max in Pilgrims of Hulu Sungai Tengah Regency

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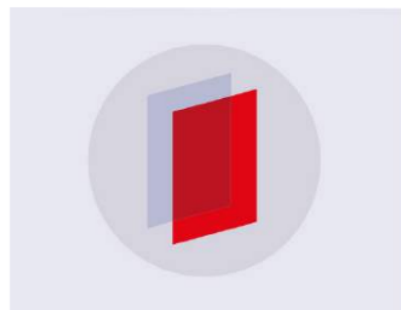


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Sustainability Strategy of Agarwood-Production Trees in Lombok Island using Harvesting Matrix

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Abstract. Eaglewood (*Gyrinops versteegii*) 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].



4
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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.

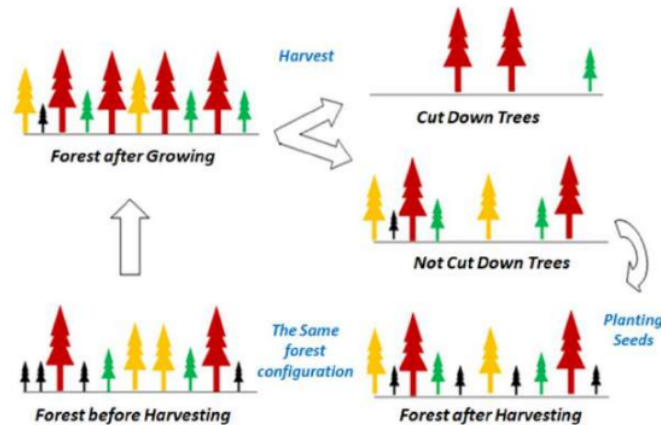


Figure 1. Sustainable Forest Harvest Cycle.

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

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

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 n th – 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 x . Since the number of trees in the forest is fixed, the following equation can be determined.

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

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 $i = 1, 2, \dots, n - 1$, 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 $n \times n$ can be formed as follows.

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

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

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

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 n th – class at the end of the growth period.

During the harvesting period, for example, y_i ($i = 1, 2, \dots, n$) number of trees taken from the i th – class. So that a vector \mathbf{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 n th – class after the end of the growth period.

So, there is a total number of $y_1 + y_2 + \dots + y_n$ 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,

$$\mathbf{R} = \begin{bmatrix} 1 & 1 & \dots & 1 \\ 0 & 0 & \dots & 0 \\ \vdots & \vdots & \dots & \vdots \\ 0 & 0 & \dots & 0 \end{bmatrix} \tag{4}$$

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

$$\mathbf{Ry} = \begin{bmatrix} y_1 + y_2 + \dots + y_n \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{5}$$

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

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

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

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]:

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

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:

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

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 $i = 1, 2, \dots, n$, then equation (11) requires that [3]:

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

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 \mathbf{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 5×5 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:

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

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

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

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

By substituting the fraction values into the matrix \mathbf{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 \mathbf{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 \mathbf{y} as the harvest vector can be written as follows:

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

\mathbf{R} is defined as a 5×5 replacement matrix.

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

So, the Ry vector becomes,

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

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

$$y_1 = 0;$$

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

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

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

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

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.

$$Gx - y + Ry = x$$

$$\begin{bmatrix} (1-g_1)x_1 \\ g_1x_1 + (1-g_2)x_2 \\ g_2x_2 + (1-g_3)x_3 \\ g_3x_3 + (1-g_4)x_4 \\ g_4x_4 + x_5 \end{bmatrix} - \begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{bmatrix} + \begin{bmatrix} y_1 + y_2 + y_3 + y_4 + y_5 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix}$$

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

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

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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PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12

PAGE 13

PAGE 14

PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20
