# [biodiv] Submission Acknowledgement

From: Ahmad Dwi Setyawan (smujo.id@gmail.com)

To: mulyadi_srm@yahoo.com

Date: Thursday, October 21, 2021 at 09:12 AM GMT+8

mulyadi mulyadi:

Thank you for submitting the manuscript, "THE GROWTH OF SENGON (paraserianthes falcataria) AT RECLAMATION SITE OF POST COAL MINING AREA IN EAST KALIMANTAN " to Biodiversitas Journal of Biological Diversity. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

Submission URL: https://smujo.id/biodiv/authorDashboard/submission/9672
Username: mulyadi

If you have any questions, please contact me. Thank you for considering this journal as a venue for your work.

Ahmad Dwi Setyawan

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Biodiversitas Journal of Biological Diversity

# [biodiv] Editor Decision

From: Smujo Editors (smujo.id@gmail.com)

To: mulyadi_srm@yahoo.com

Date: Tuesday, January 25, 2022 at 11:44 AM GMT+8

mulyadi mulyadi:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "The growth of sengon (Paraserianthes falcataria) at reclamation site of post coal mining area in east Kalimantan".

Our decision is: Revisions Required

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Reviewer A:

Notes on The growth of sengon (Paraserianthes falcataria) at three different plant ages and soil thickness on reclamation site of post coal mining area in East Kalimantan, Indonesia

General comment: This article was poorly written, so major revision has been done.

Comments were also made directly on the text.

TITLE:

Some editing was done in the title.

ABSTRACT

The Abstract has been revised considerably because the original one was poorly written.

INTRODUCTION

1. There are many redundancies and some irrelevant information; these redundancies and irrelevant information have been deleted.
2. Lines 59-51: According to the Minister of Forestry Regulation No. P.64/Menhut-II/2014 IUPPHK-RE restoration activities are carried out to restore biological elements (flora and fauna) and non-biological elements (soil, climate and topography) in an area to their original species, so that achieve biological balance and its ecosystem (Nining, et.al. 2017),...

There is no need to quote Nining et al. 2917; quote the Permenhut directly.

Like the Abstract, the introduction has been revised considerably.

MATERIALS AND METHODS

1. The methods were not written systematically. They have been revised, but some additions should be done, i.e., the formulas to calculate MAI and CAI should be given.

RESULTS AND DISCUSSION

1. Lines 161-163: The equations and curves are shown in **Figure 2** below:

**Figure 2**. Relationship between number of live plants (stems/plot).

Figure was not found.

1. Lines 170-172: The increase in the age class of land cover "did not change the soil fertility" value, but there was an increase in the values of pH, BS, C-organic, N-total, P-available and K-available until the age of 8 years, while C-organic and N-total were still continues to increase until the age of > 10 years (Wahyuni, 2013).

This statement is contradictory. The soil fertility did not change, but there were increases in pH and essential elements.

CONCLUSION

The Conclusion is too long. It has been reduced to two sentences integrated in the discussion.

Recommendation: Revisions Required

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Biodiversitas Journal of Biological Diversity

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# The growth of sengon (*Paraserianthes falcataria*) at three different plant ages and soil thickness classes on reclamation sites of post coal mining areas in East Kalimantan, Indonesia

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Manuscript received: .......(Date of abstract/manuscript submission). Revision accepted: ......

**Abstract.** Mulyadi, Ruhiyat D, Aipassa M, Hardwinanto S. 2021. The growth of *sengon* (*Paraserianthes Falcataria*) at three different plant ages and soil thicknesses on reclamation site of post-mining area in East Kalimantan, Indonesia. *Sengon* (*Paraserianthes falcataria*) is a fast- growing species commonly used for reclamation of post-coal mining areas in East Kalimantan. The study aimed to determine the impact of different thicknesses of topsoil applied at some reclamation sites after coal mining activities on the growth of *sengon*. Three coal mining companies were chosen as study areas, i.e., PT Bukit Baiduri Energi (BBE), PT. Mahakam Sumber Jaya (MSJ), and PT. Kaltim Prima Coal (KPC). The regolith soil layer at the reclamation site had three thickness classes (0-10 cm, 0-30 cm, 0-100 cm), and the *sengon* growing on reclamation had three ages, i.e., < 2 yrs old (initial growth phase), 2-5 yrs old (tending phase), and > 5 yrs old (independent growth phase). The number of surviving plants, plant height, and plant stem's diameter were recorded, and the data were analyzed using ANOVA and the least significant difference at 5% level. The results showed that no significant difference in the number of trees among different ages of sengon plantation was found at MSJ. In contrast, at BBE and KPC the number of surviving trees decreased significantly with increasing plant age. The growth of the plant (height, diameter) increased significantly along with plant age in all sites. The interaction between topsoil thickness factor and plant age factor produced no different result in plant growth except for plant height at BBE. The sengon plants had not been able to lower the surface soil density in the land reclamation area.

Key words: Pioneer vegetation, growth, mine, soil thickness, overburden, fertility, reclamation

**Running title:** Growth of Sengon (***paraserianthes falcataria***) at reclamation site

## INTRODUCTION

Almost all coal mining operations in forest concession areas in East Kalimantan caused significant forest ecosystem disturbance. Therefore, management of post-mining forest lands must be conducted thoroughly, consisting of land reshaping, topsoil spreading, mining waste treatment, soil erosion-sedimentation control, and land revegetation. These three aspects should be evaluated to assess whether the ecosystem recovery is successful or not based on the performance of land reclamation, soil erosion-sedimentation land revegetation (planted areas, growth percentage, plant species, the composition of fast-growing and long-lived species, plant health), the diversity of fungi and bacteria (Sudarmaji et al. 2021).

The natural forests have a closed nutrient cycle, and the nutrients are accumulated mainly in the forest tree biomass. If the trees are cut and the topsoil is removed, the composition of symbiotic microbes will change, so the host and the symbiotic fungi will be disconnected. Mycorrhizal fungi can only survive on the exposed forest floor in spores, mycelial hyphae, or other propagules under limited conditions. If there is an increase in temperature on the forest floor coupled with the entry of ultraviolet light, the fungal population will decrease drastically and disappear. Mycorrhiza is a biological agent that could improve soil fertility (Daras, et.al. 2015).

Coal mining in East Kalimantan use open-pit mining techniques, which should be conducted carefully due to the changes of landform, the damage of soil structure, the lack of topsoil, the change of topsoil properties, the decrease of land biodiversity, and the decline of environmental quality (Subowo 2011). The steps in mining activities include land clearing, stripping topsoil and subsoil to the parent material layer (regolith), then stripping the bedrock to the surface of the coal seam. These steps are carried out by digging bench, removing and burying the cover layer through backfilling to each mining block, and adjusting to the mineral deposit deployment (Zulkarnain et al., 2014).

The open-pit mining system caused extraordinary changes in the ecosystem in the mining area, namely the loss of natural vegetation, the opening of land (soil, source rock, and bedrock were peeled and removed), and the fauna that live in these habitats will move to a more suitable place or die (Boer 2008). These open areas must be rehabilitated immediately with fast-growing species so that the area/environment can return to its original condition.

According to the Minister of Forestry Regulation No. P.64/Menhut-II/2014 IUPPHK-RE restoration activities are carried out to restore biological elements (flora and fauna) and non-biological elements (soil, climate, and topography) in an area to their original species to achieve ecological balance.

Selection and management of pioneer plants for reclamation of degraded land are some of the keys to reclamation success (Hapsari et al. 2020). As pioneer plants, Leguminosae, such as sengon, may grow quickly and adapt to poor soil conditions with low nutrients.

In general (Pratiwi et al. 2021), the forestation process is initiated by selecting plants resistant to drought or fast-growing fodder crops that can grow with limited nutrients. The rapid closure of vegetation is important in controlling site stabilization, runoff, and erosion. When the sites have been successfully revegetated with fast-growing species, economically more valuable trees (e.g., from the family Dipterocarpaceae) should be planted based on scientific studies.

The objectives of this study were to compare the growth of *sengon* at three different plant ages and soil thicknesses on three reclamation sites of BBE, MSJ, and KPC. The results of this study may become inputs and technical references to coal mining operations management for a successful reclamation program on a post-coal mined landscape.

## MATERIALS AND METHODS

### Study area

The study area was located in Kutai Kartanegara Regency of East Kalimantan Province, Indonesia. The species and age of plants studied were determined based on the results of the preliminary survey. The study of sengon growth was conducted in three reclaimed post-coal mining sites with three different plant ages and soil thickness classes: (I) BBE sites, geographically positioned at E 117º 04' 06" S 0º 26' 58" (< 2 years old), E 117º 04' 44" S 0º 26' 13" ( 2-5 years old) and E 117º 05' 02" S 0º 26' 40" (> 5 years old), (ii) MSJ sites, E 117º 12' 53" S 0º 13' 21" (< 2 years old), E 117º 13' 46" S 0º 12' 38" ( 2-5 years old) and E 117º 08' 12" S 0º 17' 42" (> 5 years old), and KPC sites, E 117º 36' 15" S 0º 48' 37" (< 2 years old), E 117º 35' 05" S 0º 49' 02" ( 2-5 years old) and E 117º 34' 59" S 0º 50' 55" (> 5 years old). The sample plot area was 400 m2 (20 m x 20 m). In each sample plot, the number of living plants, plant height and stem diameter were recorded.

### Experimental design

Randomized Complete Block Design (RCBD) was used with a split-plot design. The main plot is the growth and productivity of crops were vegetation (V) by plant ages < 2 (V1), 2-5 years (V2), and > 5 years (V3). Sub-plot is the thickness of the surface soil (K) consisting of 3 (three) levels, namely the thickness of the surface soil < 10 cm (S1), the thickness between 0 – 30 cm (S2), and the thickness > 30 cm (S3). The thickness of the surface soil was set to 100 cm by not distinguishing between the top soiling layer and the overburden layer.

**Commented [A1]:** What does this mean? In the previous sentence, there are three thickness classes. (< 10 cm,, 0-30 cm, > 30 cm)

### Soil analysis

Soil Sample (0- 10 cm, 0-30 cm and > 30 cm thick) in each sample plot were taken for analysis in soil laboratory, Faculty of agriculture, Mulawarman University, Samarinda, East Kalimantan. Soil acidity (pH $H_20$ and KCl) was measured with electrometry pH meters; C organic content with Walkley-Black method; total-N with Kjedahl method, P and K with North Carolina method; Exchangeable base Cations ($Ca^{++}$, $Mg^{++}$, $Na^{+}$, $K^{+}$) were determined with extraction method with ammonium acetate; Texture with pipet method, and Bulk Density with Gravimetry.

### Vegetation data Analysis

The growth of plants, the Mean annual increment (MAI) and the Current annual Increment (CAI) were calculated. The following formula was used to calculate MAI:

**Commented [A2]:** The formulas to calculate MAI and CAI should be provided.

The formula to calculate CAI was:

The number of live plants from stems/plot was converted to stem/ha (N/ha), then analyzed using a formula based on the regression equation, Anova (analysis of variance) was performed to determine the difference in growth of plant, Mean annual increment (MAI) and Current annual Increment (CAI) among sites. It was followed by Least Significant Difference (LSD) test at 5% level.

## RESULTS AND DISCUSSION

**Number of living sengon**

According to the Minister of Forestry Regulation Number: P.60/Menhut-II/2009 concerning Guidelines for assessment of the Success of Forest Reclamation, revegetation activities are categorized as successful if the percentage of healthy plants is more than 80% .

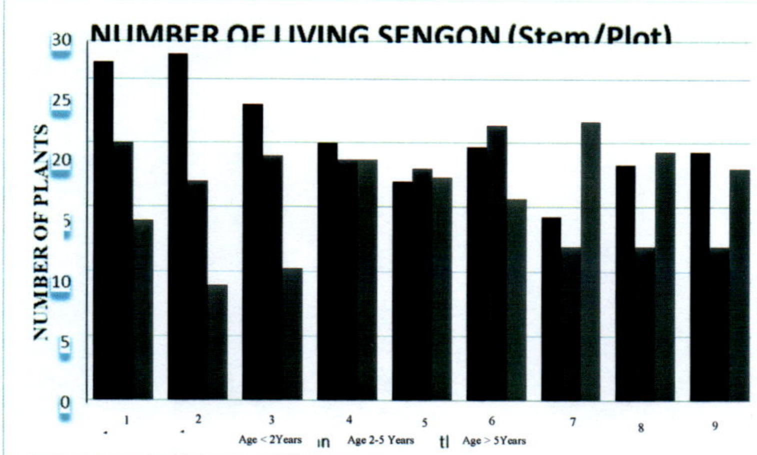



**Figure 1**. Plant number at different ages of stand

**Commented [A3]:** Y axis must have unit (stem/plot). The legend should be changed from gray scale to different pattern to distinguish among age classes.

**Table 1**. Average number of living plants (stems/plot) on different plant ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average | N/ha % |
|---|---|---|---|---|---|---|
| | | K1(SE) | K2 (SE) | K3 (SE) | | |
| PT.BBE | V1 | 26.33±1.25 | 27,00±2.17 | 23.00±3.50 | 25.44 (a) | 57.29 |
| | V2 | 20.00±1.50 | 17,00±1.00 | 19.00±1.32 | 18.67 (b) | 42.05 |
| | V3 | 14.00±1.00 | 9.00±0.50 | 10.33±0.76 | 11.11 (c) | 25.02 |
| Average | | 20.11 | 17.67 | 17.44 | | |
| PT.MSJ | V1 | 20.00±0.86 | 17,00±0.50 | 19.67±1.04 | 18.89 | 42.54 |
| | V2 | 18.67±3.17 | 18.00±1.50 | 21.33±2.46 | 19.33 | 43.53 |
| | V3 | 18.67±1.60 | 17.33±1.25 | 15.67±3.21 | 17.22 | 38.78 |
| Average | | 19.11 | 17.44 | 18.89 | | |
| PT. KPC | V1 | 14.33±1.25 | 18.33±0.28 | 19.33±0.76 | 17.33 (b) | 62.98 |
| | V2 | 12.00±1.00 | 12.00±1.32 | 12.00±0.76 | 12.00 (b) | 44.22 |
| | V3 | 21.67±0.76 | 19.33±2.02 | 18.00±3.04 | 19.67 (a) | 78.00 |
| Average | | 16.00 | 16.56 | 16.44 | | |

Numbers followed by the same letter in the same column are not significantly different in the 0.05 LSD test.

The average percentage of living plants/ha decreased with the increasing ages of vegetation: in the BBE area, they were 57.29% (V1), 42.05% (V2), and 25.02% (V3), respectively. Relatively, and in the MSJ, they were 42.54% (V1), 43.35% (V2), and 38.78% (V3). However, a different pattern was found in the KPC area, i.e., 62.98%, 44.22, and 78% (V3).[A1] Because the average percentage of living plants/ha was lower than 80%, the stability of soil aggregates was low. The soil structure of all soil reclamation profiles is determined by the type and structure of the soil-forming material layers (Khaidir et al. 2018).

The aggregate of topsoil and subsoil taken with heavy equipment can be destroyed, and the soil is easily damaged and eroded by rainwater, especially on sloping land. As a result, soil organic matter will be eroded, and the soil becomes compact. The movement of water and air affects the chemical and biological processes in the soil (Nadila and Pulunggono 2019).

The higher bulk density in undisturbed soils can be attributed to compaction from the use of heavy machinery during the replacement of soils in mined-out areas and a higher fraction of clay in reclamations soil (Ezeokoli et al. 2020).

The average soil bulk density values in reclamation area less than 2 years old was 1.48 gr/cm3 at BBE, 1.44 gr/ cm3 at MSJ and 1.49 gr/ cm3 KPC), and relatively lower at 10 cm soil thick, i.e., 1.45 gr/ cm3 BBE, 1.29 gr/ cm3 MSJ and 1.44 gr/ cm3 KPC), but this value is still considered high. The bulk density decreases with the increasing age of land reclamation due to the growth of root system and the addition of biomass. In the 15 to 20 years old post-coal mining land reclamation, the vegetation can rebuild soil structure, decrease bulk density and improve soil porosity (Noviyanto et al. 2017).

The productivity of mine soils without soil amendment [A2] is mainly limited by low nutrient availability (Anonim, 2019); Therefore, basic mineral NPK-fertilization before planting is essential. The correlation between the number of living plants and ages of vegetation (V1, V2, and V3) and the equations are shown in Figure 2.

**Figure 2**. Relationship between number of living plants (stems/plot) and ages.

**Commented [A4]:** Figire is not found.

**Plant height**

The average height of revegetation plants at different ages (V1, V2 and V3) in the land reclamation area of PT. BBE, PT. MSJ and PT. KPC was tested in relation to the thickness of the soil. The results of the analysis showed that the different ages of the vegetation caused a very significant difference in the mean height, while the thickness of the soil did not cause any difference.

There were increases in the values of pH, BS, organic-C, total-N, available-P and available-K until the age of 8 years, while the organic-C and total-N continued to increase until the age of > 10 years (Wahyuni, 2013).

**Commented [A5]:** This statement is contradictory. The soil fertility did not increase, but there were increases of pH, and essential elements.

**Table 2**. Plant height (m) at different plant ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | Average |
| PT.BBE | V1 | 6.10±1.37 | 8.50±0.91 | 7.44±0.69 | 7.35 (c) |
| | V2 | 15.49±0.63 | 13.59±0.59 | 14.45±1.20 | 14.51 (b) |
| | V3 | 24.53±1.18 | 25.63±2.18 | 27.35±1.13 | 25.84 (a) |
| Average | | 17.60 | 19.24 | 19.75 | |
| PT.MSJ | V1 | 5.26±0.41 | 5.44±0.38 | 5.89±0.41 | 5.53 (b) |
| | V2 | 19.99±1.16 | 18.8±1.84 | 20.11±1.47 | 19.66 (a) |
| | V3 | 21.26±0.75 | 21.26±1.76 | 22.89±0.67 | 21.80 (a) |
| Average | | 478 | 436 | 472 | |
| PT. KPC | V1 | 3.08±0.15 | 3.80±0.29 | 3.31±0.23 | 3.40 (c) |
| | V2 | 11.82±1.66 | 11.18±1.48 | 9.09±0.67 | 10.70 (b) |
| | V3 | 15.60±1.15 | 13.15±0.70 | 13.20±1.27 | 13.99 (a) |
| Average | | 10.21 | 9.32 | 8.59 | |

Numbers followed by the same letter in the same column are not significantly different in the 0.05 LSD test.

Plant height is influenced by genetic characters and environmental factors, such as close plant spacing which will provide higher growth due to less solar radiation. The growth rate of a stand is the result of genetic, environmental and management techniques (Ellok, 2015).

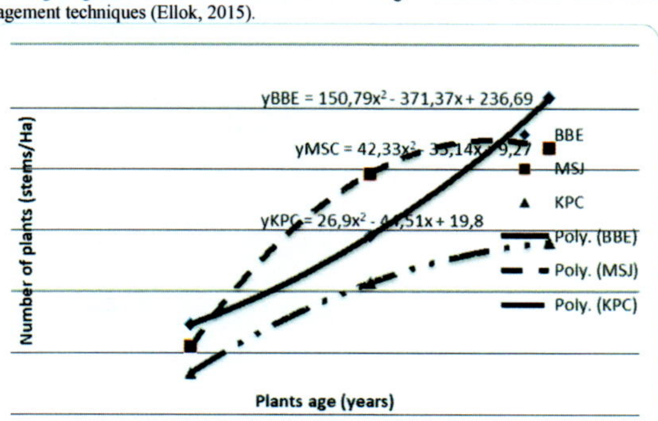



**Figure 3.** Relationship between plant height (cm) and age in mining areas.

**Commented [A6]:** The picture is plant number.

The average heights of plants in the area of KPC were 3.40 m (V1), 10.70 m (V2) and 13.99 m (V3), lower than those in the area of MSJ (5.53 m/V1, 19.66 m/V2 and 21.80 m/V3) and in the area of PT. BBE (7.35 m/V1, 14.51 (V2) and 25.84/V3).

Soil chemical properties are important for plant growth such as pH, Base Saturation and CEC. Soil pH in the area of BBE was 4.05-5.82, MSJ 5.24-5.61 and KPC 3.74-4.09. Base Saturation in BBE was 21.8 %, MSJ 43.4-52%, and KPC 17.6-41.9% . Cation Exchange Capacity was classified as low, namely 13.4-16.1cmol (+)/kg (MSJ), 10-11.2 1cmol (+)/kg (KPC) and was classified as medium, namely 17-27.4 1cmol (+)/kg (BBE).

**Commented [A7]:** Make this into a table.

The growth curve from the regression analysis in the reclamation of mining areas was relatively flat after >4 years of age, except in the BBE mining area because the vegetation age of the research plot observed in the BBE area (as determined by the Company) was than other areas. Therefore, the data on plant diameter/height was larger with the equation as shown in **Figure 3**.

With increasing age, trees will increase in height, the diameter of the canopy circle, and the unit mass of the tree. The diameter growth of broadleaf trees in the tropics occurs through all year seasons. The culmination point of the diameter increment in age-old stands was reached more quickly than the increment in height (Ruchaemi, 2013).

**Commented [A8]:** Is this statement correct, or the opposite?

The average trunk diameter in the area BBE and KPC was significantly different among age classes, while in the area of MSJ the average trunk diameter in V1 and V2 was not different but significantly different from V3.

The results of further tests with 5% LSD in the BBE area showed that the largest diameter was in V3 (35.85 cm) at 15 years old, in the MSJ (25.35 cm) at 9 years old, and KPC (18.13 cm) at 7 years old. This result is in accordance with the general growth pattern; namely, the highest tree diameter growth occurs when it has reached a diameter of 30-40 cm, then decreases gradually with increasing tree diameter (Wahyudi and Anwar 2013).

**Table 3**. Plant stem diameter (cm) at different ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | |
| PT.BBE | V1 | 19.92±4.20 | 27.55±2.12 | 23.11±1.20 | 7.50 (c) |
| | V2 | 52.80±0.14 | 46.48±0.58 | 50.85±3.77 | 15.94 (b) |
| | V3 | 110.18±7.98 | 97.99±5.86 | 129.48±5.30 | 35.85 (a) |
| Average | | 19.42 | 18.27 | 21.60 | |
| PT.MSJ | V1 | 29.91±2.49 | 31.60±3.12 | 36.03±2.68 | 10.36 (b) |
| | V2 | 44.79±10.90 | 37.33±9.06 | 44.24±10.31 | 13.41 (a) |
| | V3 | 68.94±1.63 | 77.98±3.43 | 90.77±8.36 | 25.33 (a) |
| Average | | 15.25 | 15.60 | 18.16 | |
| PT. KPC | V1 | 15.01±0.54 | 14.57±0.60 | 18.49±0.80 | 5.10 (c) |
| | V2 | 46.41±7.14 | 44.59±3.93 | 38.93±1.98 | 13.79 (b) |
| | V3 | 61.40±4.03 | 51.66±3.49 | 57.75±5.50 | 18.13 (a) |
| Average | | 13.04 | 11.76 | 12.22 | |

Numbers followed by the same letter in the same column are not significantly different in the LSD 0.05 test.

Like plant height, stem diameter growth is also affected by mixed-species planting in the area of PT. KPC, the age difference between research locations, especially on the criteria > 5 years and the chemical properties of the soil, i.e., pH (H20), Base Saturation and Cation Exchange Capacity. The lower silt fraction and organic matter content of reclamation soils were infertile (Ezeokoli et al. 2020).

The plant diameter growth curve is a mathematical model of a curve that describes the growth of plants in the stand, starting from being planted to reaching maturity (Riyanto and Pamungkas, 2010)

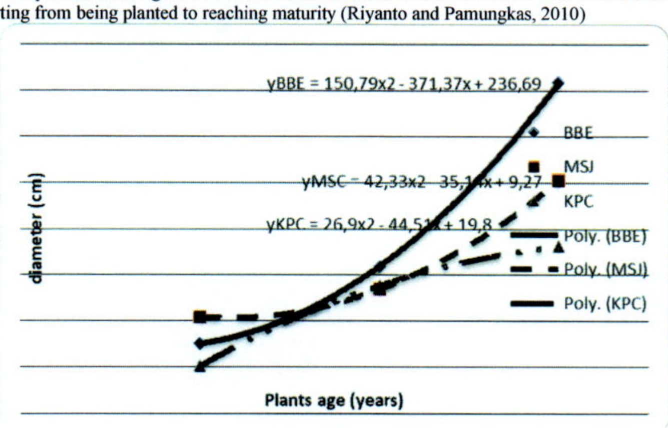
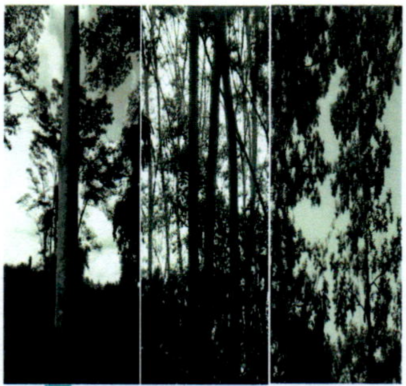



**Figure 4**. Growth of sengon (BBE, MSJ and KPC) aged > 5 years.

Figure 5 shows that the revegetation plant has a growth trend in line with increasing age, and the largest is in the PT. BBE. The KPC trend declines after the age of 8 years. The amount of leaf biomass of vegetation increased until the age of

7 years and decreased after 9 years. In contrast, sungkai increased at the age of 4 years and decreased after more than 5 years (Murtinah and Komara, 2019). In general (Adman et al. 2020), all species observed have slow growth in height and diameter in the first year after planting. In the following years, there was an acceleration in both height and diameter growth at various rates.



(a) (b) (c)

**Figure 5**. Growth of sengon at BBE (a), MSJ (b) and KPC (c) aged > 5 years.

**Volume**

The growth rate of a stand is the result of genetic, environmental, and management techniques (Ellok, 2015). The analysis results showed that the differences in vegetation age, soil thickness, and their interactions caused significant differences in the volume of trees in the land reclamation area of BBE. In contrast, in the area of MSJ and KPC only the age difference of the vegetation had a significant effect on the volume of trees.

The average of the highest volume was found V3 treatment in land reclamation area of BBE (479.69 m3/ha), followed by MSJ (284.82 m3/ha) and PT. KPC (128.37 m3/ha). The difference in the calculated volume of vegetation was not only caused by the different number of trees aged > 5 years (V3) among the three locations, which was quite significant, but it was also due to differences in ages of plant and soil properties in the reclamation area of each company's mining area.

**Table 4.** Volume ($m^3$/ha) at different plant ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | |
| PT.BBE | V1 | 12.11±6.90 | 25.21±5.69 | 13.43±3.78 | 16.11 (c) |
| | V2 | 119.53±4.50 | 70.44±8.23 | 101.36±21.2 | 97.11 (b) |
| | V3 | 495.23±44.56 | 289.62±35.69 | 654.22±36.0 | 479.69(a) |
| Average | | 208.96 (a) | 128.42 (c) | 256.34(b) | |
| PT.MSJ | V1 | 13.63±3.17 | 13.45±2.86 | 22.29±5.66 | 16.46 (c) |
| | V2 | 133.75±65.88 | 63.43±18.57 | 127.77±44.1 | 108.31 (b) |
| | V3 | 260.20±12.12 | 205.79±98.9 | 388.47±40.5 | 284.82 (a) |
| Average | | 135.86 | 94.22 | 179.51 | |
| PT. KPC | V1 | 1.37±0.06 | 2.10±0.32 | 3.09±0.41 | 2.19 (c) |
| | V2 | 47.80±15.4 | 43.41±14.9 | 23.94±6.29 | 38.38 (b) |
| | V3 | 181.40±29.5 | 91.37±7.98 | 112.35±29.2 | 128.37 (a) |
| Average | | 76.86 | 45.63 | 46.46 | |

Numbers followed by the same letter in the same column are not significantly different in the LSD test of 0.05.

Low Volume ($m^3$/ha) in PT. KPC was caused by mixed cropping, while at the location of PT. BBE and PT. MSJ only single species was planted. In order to obtain uniformity, then only the plant height and stem diameter of sengon/plot was used for calculation **(Table 4)**.

The average volume ($m^3$/ha) of *sengon* in the area of KPC was generally lower, except for V3 which was around 128.37 $m^3$/ha.

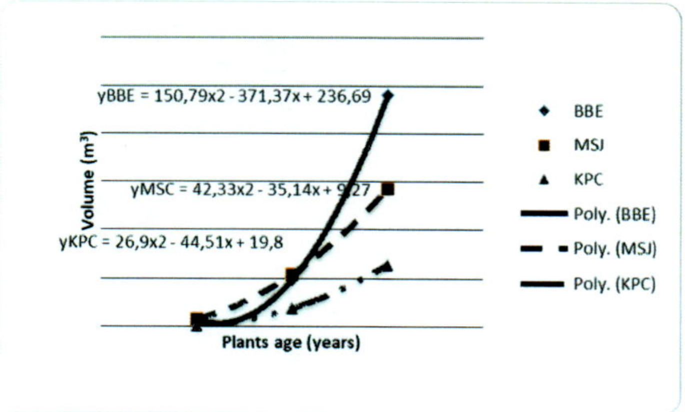



**Figure 6**. Relationship between Volume (m3/ha) and age in Mining and Non-Mining areas.

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The high volume ($m^3$/ha) was due to low sampling plant used as the basis for calculation of the height and trunk diameter (about 3-7 stems of plants/plot), resulting in the disproportionate average value of height and large diameter stem. *Sengon* litter (liter fall) contributes nutrients to the soil, i.e., C, N, P about 4291 kg/ha, 973 kg/ha, and 794 kg/ha per year (Sudomo and Widiyanto 2017). The largest macronutrient in *sengon* stands was Calcium (0.28 %), Nitrogen (0.23 %), Potassium (0.19 %), Phosphorus (0.08%), and the lowest was Magnesium at around 145.52 ppm (Herwanto et al. 2016).

The low soil fertility in the PT.KPC land reclamation area was due to the sulfate solution found around plot V2. The shallower pyrite significantly decreased soil pH and increased Al and relatively decrease K, Ca, Mg, Cu and Zn (Sutandi, et.al. 2011).

**Figure 7**. Dissolved sulfate ($FeSO_4$) in the V3 border plot of KPC.

**Mean Annual Increment (MAI)**

The annual mean increment (MAI) is the quotient between total production and stand age (Ruchaemi, 2013). The stand potential calculation was done by calculating the volume based on the volume table. Riyanto and Pamungkas, (2010) states that the results of the stand volume calculation are needed to determine the standing stock of each age class, then from the standing stock calculation results, the stand volume increment is calculated in one cycle. This volume increment can be divided into an annual average increment (MAI) and a current average increment (CAI).

**Table 6.** Mean Annual Increment (MAI) at different plant ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 | K2 | K3 | |
| PT.BBE | V1 | 8.90±5.07 | 12.16±2.74 | 6.38±1.79 | 7.66 |
| | V2 | 24.12±0.90 | 13.94±1.62 | 19.79±4.14 | 19.28 |
| | V3 | 33.50±3.03 | 19.26±2.39 | 44.05±2.41 | 32.27 |

| | | | | | |
|---|---|---|---|---|---|
| Average | | 22.17 | 15.12 | 23.41 | |
| PT.MSJ | V1 | 46.57±1.53 | 6.45±1.37 | 10.48±2.66 | 7.83 |
| | V2 | 23.19±11.46 | 14.67±4.30 | 26.02±9.00 | 21.29 |
| | V3 | 29.24±1.37 | 22.95±11.17 | 45.80±4.54 | 32.66 |
| Average | | 19.67 | 14.69 | 27.43 | |
| PT. KPC | V1 | 0.93±0.04 | 1.37±0.21 | 1.85±0.24 | 1.38 |
| | V2 | 10.175±3.29 | 9.3±3.22 | 5.76±1.51 | 8.41 |
| | V3 | 24.59±4.02 | 14.47±1.26 | 18.24±4.76 | 19.1 |
| Average | | 11.90 | 8.38 | 8.62 | |

Table 6 shows that MAI increased with age at each research location, but the largest occurred in the MSJ, followed by BBE and f KPC. Research Patiun et al. (2011) in Zulkarnain et al. (2014) showed that until the reclamation age of 15 years with acacia vegetation, the soil permeability was still low, i.e., 12.03 cm/hour at 0 - 15 cm depth and 2.49 cm/hour at 15 - 30 cm depth. This indicates that the change in soil compaction affected the soil permeability up to 15 years age of reclamation.

Various experiences and best practice in the implementation of post-mining reclamation show that degraded ex-mining land might become productive again (Pratiwi et al. 2021); The success of post-mining reclamation in restoring tropical forest cover can also support the conservation of biodiversity through the provision of animal habitats that lead to or approach their natural condition. . In conclusion, this study found that the diameter and height of *sengon* increased with the increasing age, but the number of surviving trees declined. In contrast, soil thickness had no siginifcant effect on the *sengon* growth


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# The growth of sengon (*Paraserianthes falcataria*) at three different plant ages and soil thickness classes on reclamation sites of post coal mining areas in East Kalimantan, Indonesia

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**Abstract.** Mulyadi, Ruhiyat D, Aipassa M, Hardwinanto S. 2021. The growth of Sengon *sengon* (*Paraserianthes Falcataria*) at three different plant ages and soil thicknesses on reclamation site of post-mining area in East Kalimantan. *Sengon* (*Paraserianthes falcataria*) is a fast- growing species spesies that is commonly used use as a pioneer vegetation tofor reclamation of post-coal mining areas in East Kalimantan. The study was aimed to find outdetermine the impact of different thicknesses of top-soiling applied at some reclamation sites after coal mining activities to on the growth of Sengon *sengon* (paraserianthes *falcataria*) plants. Three coal mining companies were choosen as study areas, i.e., PT Bukit Baiduri Energi (BBE), PT. Mahakam Sumber Jaya (MSJ), and PT. Kaltim Prima Coal (KPC). The thickness of regolith soil layer at the reclamation site were consist ofhad three thickness classes (0-10 cm, 0-30 cm, 0-100 cm), whereas and the *sengon* growing on reclamation sites were differentiated based on theirhad three ages, into i.e., < 2 yrs old (initial growth phase), 2-5 yrs old (tending phase), and - > 5 yrs old (independent growth phase). The plant growth measured included number of survival surviving plants, plant height, and plant stem's diameter on plot of 20 x 20 mwere recorded, and the data were analyzed using ANOVA and the least significant difference at 5% level. - Data analysis was performed using ANOVA and if the data significant continued with LSDA 5%. The results show that the existence of sengon plants have not been able to the lower the density of the surface soil layer of the land reclamation area. showed that No no significant different difference in the number of trees among different ages of sengon plantation was found at MSJ. In contrast, while at BBE and KPC the number of survival surviving trees reduced decreased significantly by with the increasing plant age.. No significant different in the number of threes among different age of plants found at MSJ while at BBE and KPC the number of of survival trees reduced significantly by increasing plant age and The Growth growth of the plant (height, diameter) at MSJ were increased significantly along with plant age while at BBE and KPC the increasing were even very significantin all sites. The interaction between top soiling thickness factor and plant age factor produced no different result in plant growth except for plant height at BBE. The sengon plants had not been able to lower the surface soil density in the land reclamation area.

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Key words: Pioneer vegetation, growth, mine, soil thickness, overburden, fertility, reclamation

**Running title:** Growth of Sengon (***paraserianthes falcataria***) at reclamation site

## INTRODUCTION

Almost all coal Mining mining operations of East Kalimantan in the forest concession areas in East Kalimantan caused significant forest ecosystem disturbance. Therefore, management of mined-outpost-mining forest lands must be conducted thoroughly, following consisting of land reshaping -clearing, topsoils spreading, mining waste treatment, soil erosion-sedimentation control, land rehabilitation (reclamation and Revegetation). Concerning expected ecosystem recovery, mined-out forest lands rehabilitation must be carried out covering land arrangement, soil erosion-sedimentation control, and land revegetation. These three aspects were should be evaluated to assess whether the ecosystem recovery is successful or not based on the performance of land reclamation, soil erosion-sedimentation land revegetation (planted areas, growth percentage, plant species, the composition of fast-growing and long-lived species, plant health), the diversity of fungi/fungus and bacteria (Sudarmaji, et. al. 2021).

The characteristics of natural forests are that they have a closed nutrient cycle, and the accumulation of nutrients is are found accumulated mainly in the forest tree biomass. -iIf the trees are cut down and the topsoil is removed, there will be a change in the microbial composition of , especially in symbiotic microbes will change, so that there will be a disconnect between the host and the symbiotic fungi will be disconnected. where mMycorrhizal fungi can only survive on the exposed forest floor in the form of spores, mycelial hyphae, or other propagules under limited conditions. If there is an increase in temperature and humidity on the forest floor coupled with the entry of ultraviolet light, it can be ascertained that the fungal population will decrease drastically and disappeardie. Mycorrhiza is a biological agent that could improve the soil fertility (Daras~~,~~ et ~~.~~al. 2015) ~~and the application of that mycorrhizal fungi and soil ameliorant play an essensial aspect in increasing the growth of vegetation.~~.

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Coal ~~mines~~ mining in East Kalimantan use open-pit mining techniques, which ~~(open pit mining system). Open pit mining~~ should be conducted carefully due to the ~~conversion~~changes -of landform, the damage of soil structure, the lack of top-soil, the change of top-soil ~~ecosystem equilibrium~~properties, the decrease of ~~land~~ biodiversity, and the ~~reduce~~ declined of emvironmental quality (Subowo~~,~~ 2011).

The steps ~~taken~~ in mining ~~activity~~ activities include land clearing, stripping top-soil and subsoil to the parent material layer (regolith), then stripping the bedrock to the surface of the coal seam.~~, this method implemented by coal companies in East Kalimantan. Its~~ These steps are carried out by digging bench, removing and burying the cover layer through backfilling to each mining block, and adjusting to the mineral deposit deployment (Zulkarnain~~,~~ et~~.~~ ~~Al~~al.~~,~~ 2014).

The ~~impact of the~~ open-pit mining system caused extraordinary changes in the ecosystem in the mining area, namely the loss of natural~~/forest~~ vegetation, the opening of land (soil, source rock, and bedrock were peeled and removed), ~~as well as~~and the fauna that live~~d~~ in these habitats ~~were mostly extinct and some moved~~will move to a more suitable place or die (Boer~~,~~ 2008). These open areas must be rehabilitated immediately with fast~~-~~ growing species so that the area/environment can return to ~~or approach~~ its original condition.

According to the Minister of Forestry Regulation No. P.64/Menhut-II/2014 IUPPHK-RE restoration activities are carried out to restore biological elements (flora and fauna) and non-biological elements (soil, climate, and topography) in an area to their original species~~, so that~~ to achieve ~~biological~~ ecological balance ~~and its ecosystem (Nining, et.al. 2017), so the use of mining land must also refer to this regulation.~~.

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Selection and management of pioneer plants for reclamation of degraded land ~~is~~ are ~~very important, and become one~~ some of the keys to reclamation success (Hapsari~~,~~ et ~~.~~al. 2020~~),~~ ). As pioneer plants, Leguminosae, such as ~~a pioneer plants (Sengon)~~sengon, may ~~be~~ grow quickly and adapt~~able~~ to poor soil conditions with ~~lack~~ low nutrients.

In general (Pratiwi~~,~~ et al. 2021), the ~~a~~ forestation process is initiated by selecting plants resistant to drought or fast-growing fodder crops that can ~~be~~ grow with limited nutrients. ~~and rapid growth, as t~~The rapid closure of vegetation is important in controlling site stabilization, runoff, and erosion. When the sites have been successfully revegetated with fast-growing species, economically more valuable trees (e.g., from the family Dipterocarpaceae) should be planted based on scientific studies.

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~~A set of science-base best management practices for post-coal mine reforestation is needed to develop to promote the success of forest reclamation and restoration in post-coal mining lands through the planting of high value hardwood tress (Dypterocarpaceae sp) after revegetation by pioneer plants success and micro climate have been support to planting trees. Therefore, this study aimed to find out the impact of different thickness of top soil (regolith) apllied at some reclamation sites after coal mining activities to the growth of Sengon plants.~~

The objectives of this study were to ~~access and~~ compare the growth of ~~Sengon~~ *sengon* at three different plant ages and soil thicknesses on three reclamation sites of BBE, MSJ, and KPC. The results of this study may become inputs and technical references to coal mining operations management for a successful reclamation program on a post-coal mined landscape~~, soil physic and fertility characteristics~~.

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## MATERIALS AND METHODS

### Study area

The study area was located in Kutai Kartanegara Regency of East K~~k~~alimanatan Province, Indonesia. The species and age of plants studied ~~Field surveys in the form of descriptive and experimental research~~ were determined based on the results of the preliminary survey.~~, namely by determining the age and type of plant to be studied, because of company permission, this researched taken time twelve month.~~ The study of sengon growth ~~of Sengons studies were~~was conducted in three reclaimed post-coal mining ~~sited~~ sites with three different plant ages and soil thickness classes: (I) BBE sites, ~~geographyeally~~geographically positioned at E 117º 04' 06" S 0º 26' 58" (< 2 years old), E 117º 04' 44" S 0º 26' 13" ( 2-5 years old) and E 117º 05' 02" S 0º 26' 40" (> 5 years old) , (ii) MSJ sites, E 117º 12' 53" S 0º 13' 21" (< 2 years old), E 117º 13' 46" S 0º 12' 38" ( 2-5 years old) and E 117º 08' 12" S 0º 17' 42" (> 5 years old) , and KPC sites, E 117º 36' 15" S 0º 48' 37" (< 2 years old), E 117º 35' 05" S 0º 49' 02" ( 2-5 years old) and E 117º 34' 59" S 0º 50' 55" (> 5 years old). The ~~area of the~~ sample plot area ~~is~~ was 400 $m^2$~~, in the form of a square with a size of~~ (20 m x 20 m). In each sample plot, the number of living plants, plant height and stem diameter were ~~calculated~~recorded.

### Experimental design

Randomized Complete Block Design (RCBD) was used with a split plot design. The main plot is the growth and productivity of crops were vegetation (V) by plant ages < 2 (V1), 2-5 years (V2) and > 5 years (V3). Sub-plot is the thickness of the surface soil (K) consisting of 3 (three) levels, namely the thickness of the surface soil < 10 cm (S1), the thickness between 0 – 30 cm (S2) and the thickness > 30 cm (S3). The thickness of the surface soil was set to 100 cm by not distinguishing between the top soiling layer and the overburden layer.

**Commented [A2]:** What does this mean? In the previous sentence, there are three thickness classes. (< 10 cm,, 0-30 cm, > 30 cm)

**Soil analysis**

Soil Sample (0- 10 cm, 0-30 cm and > 30 cm thick) in each sample plot were taken ~~as soil samples~~ for ~~further~~ analysis in soil laboaratory, Faculty of agriculture, Mulawarman University, Samarinda, East Kalimantan. Soil acidity (pH $H_20$ and KCl) was measured ~~by~~ with electrometry pH meters; C organic content ~~by~~ with ~~walkley~~Walkley-~~black~~ Black method; total-N ~~total~~ ~~by~~ with Kjedahl method, P and K ~~by~~ with North Carolina method; Exchangeable base Cations ($Ca^{++}$, $Mg^{++}$, $Na^{+}$, $K^{+}$) were determined ~~by~~ with extraction method with ammonium acetate; Texture ~~by~~ with pipet method, ~~snd~~ and Bulk Density ~~by~~ with Gravimetry.

**Vegetation data Analysis**

The growth of plants, the Mean annual increment (MAI) and the Current annual Increment (CAI) were calculated. The following formula was used to calculate MAI:

**Commented [A3]:** The formulas for MAI and Cai should be provided.

The formula to calculate CAI was:

The number of live plants from stems/plot was converted to stem/ha (N/ha), then analyzed using a formula based on the regression equation,

~~Randomized Complete Block Design (RCBD) used by split plot design.~~ Anova (analysis of variance) was performed to ~~identify~~ determine the difference in growth of plant, Mean annual increment (MAI) and Current annual Increment (CAI) among sites. It was followed by Least Significant ~~Different~~ Difference (LSD) test at 5% ~~test~~level. ~~The Anova result tables will not shown, but the results of lest Significant Different will be shown in tables, and the statistical difference will be distingushed by letters. CAI measured at plant ages ( initial growth phase, tending phase and independent growth phase) and MAI calculated by formula Y $^{(t)}$/t) where Y $^{(t)}$ at time t.~~

~~The main plot is the growth and productivity of crops were vegetation (V) by plant ages < 2 (V1), 2-5 years (V2) and > 5 years (V3). Sub-plot is the thickness of the surface soil (K) consisting of 3 (three) levels, namely the thickness of the surface soil < 10 cm (S1), the thickness between 0 – 30 cm (S2) and the thickness > 30 cm (S3). The thickness of the surface soil is set to a thickness of 100 cm by not distinguishing between the top soiling layer and the overburden layer.~~

## RESULTS AND DISCUSSION

**Number of living ~~Sengon~~ sengon ~~(stems/plot)~~**

According to the Minister of Forestry Regulation Number: P.60/Menhut-II/2009 concerning Guidelines for assessment of the Success of Forest Reclamation, revegetation activities are categorized as successful if the percentage of healthy plants ~~life and health~~ is more than 80% ~~(Widiyatmoko, et.al. (2017)~~.

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~~When making the research plot, the age difference was determined based on the criteria of < 2 years, 2 – 5 years and > 5 years, it turned out that in the field the age of the plants determined by BBE to be studied were V1 (2 years), V2 (5 years) and V3 (15 years).~~

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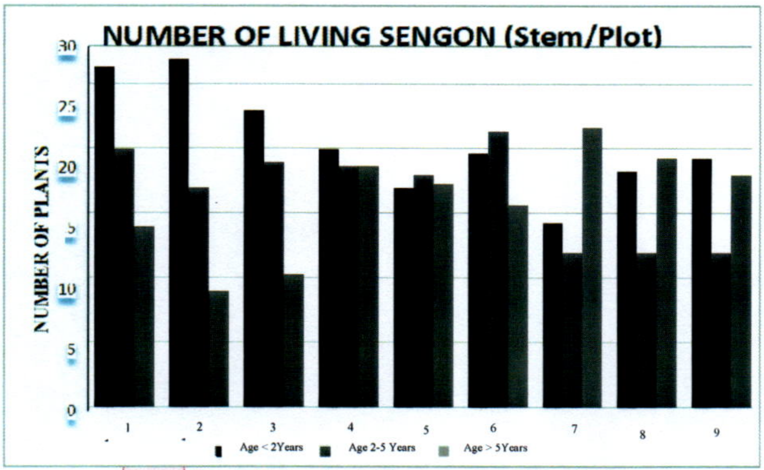


**Figure 1**. Diagram Plant number at different ages of stand (Stems/Plot)

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While in the area of plant age PT.MSJ at V1 (2 years), V2 (4.5 years) and V3 (9 years) and in the area of KPC is V1 (1.5 years), V2 (4 years) and V3 (7 years).

**Table 1**. Average number of living plants (stems/plot) ~~based~~ on different plant ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average | N/ha % |
|---|---|---|---|---|---|---|
| | | K1(SE) | K2 (SE) | K3 (SE) | | |
| PT.BBE | V1 | 26.33±1.25 | 27,00±2.17 | 23.00±3.50 | 25.44 (a) | 57.29 |
| | V2 | 20.00±1.50 | 17,00±1.00 | 19.00±1.32 | 18.67 (b) | 42.05 |
| | V3 | 14.00±1.00 | 9.00±0.50 | 10.33±0.76 | 11.11 (c) | 25.02 |
| Average | | 20.11 | 17.67 | 17.44 | | |
| PT.MSJ | V1 | 20.00±0.86 | 17,00±0.50 | 19.67±1.04 | 18.89 | 42.54 |
| | V2 | 18.67±3.17 | 18.00±1.50 | 21.33±2.46 | 19.33 | 43.53 |
| | V3 | 18.67±1.60 | 17.33±1.25 | 15.67±3.21 | 17.22 | 38.78 |
| Average | | 19.11 | 17.44 | 18.89 | | |
| PT. KPC | V1 | 14.33±1.25 | 18.33±0.28 | 19.33±0.76 | 17.33 (b) | 62.98 |
| | V2 | 12.00±1.00 | 12.00±1.32 | 12.00±0.76 | 12.00 (b) | 44.22 |
| | V3 | 21.67±0.76 | 19.33±2.02 | 18.00±3.04 | 19.67 (a) | 78.00 |
| Average | | 16.00 | 16.56 | 16.44 | | |

Numbers followed by the same letter in the same column ~~indicate that the difference is~~are not significantly different in the 0.05 LSD test.

The average percentage of ~~live~~ living plants/ha ~~tends to~~ decreased with the ~~treatment of different~~increasing ages of vegetation in the BBE area, they were ~~which is only about~~ 57.29% (V1), 42.05% (V2), and 25.02% (V3), respectively. Relatively, and in the ~~same in the area of~~ MSJ they were 42.54% (V1), 43.35% (V2), and 38.78% (V3). ~~, but~~ However, a different pattern was found ~~from the number of plants~~ in the KPC area, i.e., ~~is~~ 62.98%, 44.22 and 78% (V3). Because ~~The~~ the average percenatage of ~~live~~ living plants/ha was lower than 80%, ~~cause~~ the stability of soil aggregates was low. The ~~grade of~~ soil structure ~~on~~ of all ~~of the~~ soil reclamation profiles is determined by the type and structure of the soil-forming material layers ~~structure and compaction~~ (Khaidir, et al. 2018).

The aggregate of top-soil and subsoil taken with heavy equipment ~~that~~ can be destroyed ~~the aggregates that have been formed. Therefore,~~and the soil ~~was~~ is easily damaged and eroded by rain water ~~and easily eroded~~, especially on sloping land. ~~so~~As a result, ~~that~~ soil organic matter will be eroded, and the soil becomes compact. ~~The m~~Movement of water and air ~~is bad and~~ affects the chemical and biological processes ~~of~~ in the soil (Nadila and Pulunggono, 2019).

The higher ~~of~~ bulk density in undisturbed soils can be attributed to compaction from the use of heavy machinery during the replacement of soils in mined-out areas, and a higher fraction of clay~~ey~~ in reclamations soil (Ezeokoli, et al. 2020). ~~and they are similar to observations made in earlier studies on reclamation area.~~

The average soil bulk density values ~~age of land less than 2 years old~~ in ~~soil~~ reclamation area less than 2 years old ~~showed that the average~~a was ~~soil bulk density value (~~ 1.48 gr/~~cc~~ $cm^3$ at BBE, 1.44 gr/ $cm^3$~~cc~~ at MSJ and 1.49 gr/ $cm^3$~~cc~~ KPC), ~~; but~~ and ~~more~~ relatively lower at 10 cm soil thick, i.e., ~~(~~1.45 gr/ $cm^3$~~cc~~ BBE, 1.29 gr/ $cm^3$~~cc~~ MSJ and 1.44 gr/ $cm^3$~~cc~~ KPC), ~~at 10 cm soil thick~~ but this value is still considered high ~~density of soils~~. The bulk density decreases with the increasing age of land reclamation ~~and~~ due to the growth of root system and the addition of biomass. ~~in~~ In the 15 to 20 years old post-coal mining land reclamation, the vegetation can rebuild soil structure, decrease bulk density and improve soil porosity (Noviyanto, et al. 2017).

The ~~bio-~~productivity of ~~virgin~~ mine soils without soil amendement is ~~mostly~~ mainly limited in by ~~a very~~ low nutrient availability (Anonim, 2019); Therefore, ~~a growth supporting and soil life triggering~~ basic mineral NPK-fertilization before planting is essential. ~~The number of live plants from stems/plots was converted to stem/ha (N/ha), then analyzed using a formula based on the regression equation,~~ The correlation between ~~it was seen that the~~ number of ~~live~~ living plants ~~against~~ and ~~different~~ ages of vegetation (V1, V2, and V3) and the equations are shown in Figure 2. ~~The equations and curves are shown in **Figure 2** below:~~

**Figure 2**. Relationship between number of ~~live~~ living plants (stems/plot) and ages.

**Plant height** ~~(m)~~

The average height of revegetation plants ~~of~~ at different ages (V1, V2 and V3) in the land reclamation area of PT. BBE, PT. MSJ and PT. KPC was tested in relation ~~to~~ in the thickness of the soil. The results of the analysis ~~of diversity~~ showed that the different ages of the vegetation caused a very significant difference to the mean height, while the thickness of the soil did not ~~show~~ cause any difference.

**Commented [A7]:** Was the initial number of plants was the same? Did they plant the same number of plants in the beginning?

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**Commented [A8]:** What is virgin mine soils?

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There ~~increase in the age class of land cover did not change the soil fertility value, but there was an~~were increases in the values of pH, BS, organic-C~~-organic~~, total-N~~-total~~, available-P~~-available~~ and available-K~~-available~~ until the age of 8 years, while the organic-C~~-organic~~ and total-N~~-total~~ ~~were still continues~~ continued to increase until the age of > 10 years (Wahyuni, 2013).

**Commented [A10]:** This statement is contradictory. The soil fertility did not increase, but there were increases of pH, and essential elements.

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**Table 2**. Plant height (m) ~~based on~~at different plant ages (V) and soil thicknesses (K).

| | V Factor | K1 (SE) | K2 (SE) | K3 (SE) | Average |
|---|---|---|---|---|---|
| PT.BBE | V1 | 6.10±1.37 | 8.50±0.91 | 7.44±0.69 | 7.35 (c) |
| | V2 | 15.49±0.63 | 13.59±0.59 | 14.45±1.20 | 14.51 (b) |
| | V3 | 24.53±1.18 | 25.63±2.18 | 27.35±1.13 | 25.84 (a) |
| Average | | 17.60 | 19.24 | 19.75 | |
| PT.MSJ | V1 | 5.26±0.41 | 5.44±0.38 | 5.89±0.41 | 5.53 (b) |
| | V2 | 19.99±1.16 | 18.8±1.84 | 20.11±1.47 | 19.66 (a) |
| | V3 | 21.26±0.75 | 21.26±1.76 | 22.89±0.67 | 21.80 (a) |
| Average | | 478 | 436 | 472 | |
| PT. KPC | V1 | 3.08±0.15 | 3.80±0.29 | 3.31±0.23 | 3.40 (c) |
| | V2 | 11.82±1.66 | 11.18±1.48 | 9.09±0.67 | 10.70 (b) |
| | V3 | 15.60±1.15 | 13.15±0.70 | 13.20±1.27 | 13.99 (a) |
| Average | | 10.21 | 9.32 | 8.59 | |

(K Factor spans K1–K3 and Average.)

Numbers followed by the same letter in the same column ~~, states that the difference is~~are not significantly different in the 0.05 LSD test.

Plant height is influenced by genetic characters and ~~, however,~~ environmental factors ~~can affect plant height~~, such as close plant spacing which will provide higher growth due to less solar radiation. The ~~fast and slow~~ growth rate of a stand is ~~a~~ the result of genetic, environmental and management techniques (Ellok, 2015).

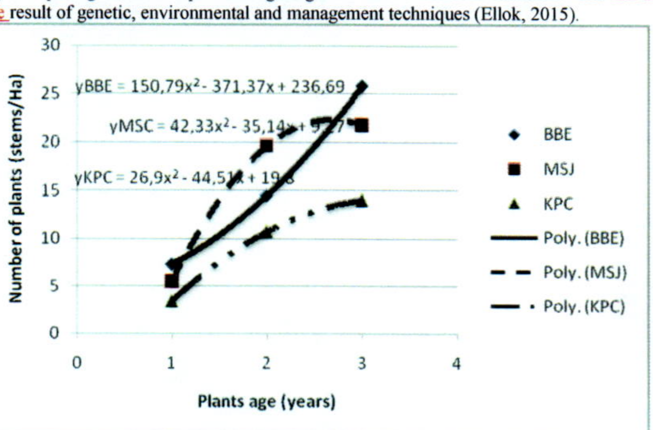


**Figure 3.** Relationship between plant height (cm) and age in mining areas.

**Commented [A11]:** The picture is plant number.

The ~~low growth is particularly high standing crops in~~average heights of plants in the area of KPC ~~is an average of about~~were 3.40 m (V1), 10.70 m (V2) and 13.99 m (V3), lower than those ~~compared to~~in the area of MSJ (5.53 m/V1, 19.66 m/V2 and 21.80 m/V3) and in the area of PT. BBE (7.35 m/V1, 14.51 (V2) and 25.84/V3). ~~besides being caused by differences in plant species, differences in the age of vegetation on the established criteria (>5 years), also quite influential are chemical properties and soil fertility.~~

Soil chemical properties are important for plant growth such as pH, Base Saturation and CEC. Soil pH ~~content~~ in the area of BBE ~~(was~~ 4.05-5.82~~)~~, MSJ ~~(~~5.24-5.61~~)~~ and KPC ~~(~~3.74-4.09~~)~~, ~~while~~ Base Saturation ~~is~~ in BBE ~~(was~~ 21.8 %~~)~~, MSJ

~~(~~43.4-52%,~~)~~ and KPC ~~(~~17.6-41.9% ~~)~~. Cation Exchange Capacity ~~(cmol (+) per Kg Soil)~~ was~~is~~ classified as low, namely 13.4-16.1cmol (+)/kg (MSJ), 10-11.2 1cmol (+)/kg (KPC) and ~~is~~ was classified as medium, namely 17-27.4 1cmol (+)/kg (BBE).

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The growth curve ~~results of~~ from the regression analysis ~~of~~in the reclamation of mining areas ~~depict~~ was ~~a~~ relatively flat ~~growth regression curve~~ after >4 years of age, except in the BBE mining area because ~~. This is due to the fact that~~ the vegetation age of the research plot observed in the BBE area (as determined by the Company) ~~is~~ was ~~longer~~ older than other areas.~~;~~ Therefore, ~~so~~ the data on plant diameter/height is larger with the equation as shown in **Figure 3** ~~above~~.

~~Tree w~~With increasing age, trees will increase in height, the diameter of the canopy circle and the unit mass of the tree. The diamaeter growth of ~~the thickness (diameter) of~~ broadleaf trees in the tropics ~~knows no time, meaning that it~~ occurs through ~~every~~ all year seasons ~~of the year~~. The culmination point of the diameter increment in age-old stands was reached more quickly than the increment in height (Ruchaemi~~,~~ 2013).

Commented [A13]: Is this statement correct, or the opposite?

~~Based on the results of the analysis of t~~The average trunk diameter in the area BBE and KPC ~~results from the treatment of different ages of vegetation caused a very~~was significantly ~~difference in stem diameter~~different among age classes, while in the area of MSJ ~~showed that the age of vegetation~~the average trunk diameter ~~(~~in V1 and V2~~)~~ was not different~~,~~ but significantly different from V3.

The results of further tests with 5% LSD in the BBE area showed that the largest diameter was in V3 (35.85 cm) at 15 years old, ~~as well as~~ in the MSJ (25.35 cm) at 9 years old, and KPC (18.13 cm) at 7 years old. This ~~data~~ result is in accordance with general growth pattern;~~,~~ namely the highest tree diameter growth occurs when it has reached a diameter of 30-40 cm, then decreases gradually with increasing tree diameter (Wahyudi and Anwar~~,~~ 2013).

**Table 3**. Plant stem diameter (cm) ~~based on~~at ~~plant~~ different ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | |
| PT.BBE | V1 | 19.92±4.20 | 27.55±2.12 | 23.11±1.20 | 7.50 (c) |
| | V2 | 52.80±0.14 | 46.48±0.58 | 50.85±3.77 | 15.94 (b) |
| | V3 | 110.18±7.98 | 97.99±5.86 | 129.48±5.30 | 35.85 (a) |
| Average | | 19.42 | 18.27 | 21.60 | |
| PT.MSJ | V1 | 29.91±2.49 | 31.60±3.12 | 36.03±2.68 | 10.36 (b) |
| | V2 | 44.79±10.90 | 37.33±9.06 | 44.24±10.31 | 13.41 (a) |
| | V3 | 68.94±1.63 | 77.98±3.43 | 90.77±8.36 | 25.33 (a) |
| Average | | 15.25 | 15.60 | 18.16 | |
| PT. KPC | V1 | 15.01±0.54 | 14.57±0.60 | 18.49±0.80 | 5.10 (c) |
| | V2 | 46.41±7.14 | 44.59±3.93 | 38.93±1.98 | 13.79 (b) |
| | V3 | 61.40±4.03 | 51.66±3.49 | 57.75±5.50 | 18.13 (a) |
| Average | | 13.04 | 11.76 | 12.22 | |

Numbers followed by the same letter in the same column ~~indicate that the difference is~~are not significantly different in the LSD 0.05 test.

~~As well as~~Like plant height, stem diameter ~~stand~~ growth is also affected by mixed-species ~~Cropping~~ planting ~~systems~~ in the area of PT. KPC ~~(Cropping pattern) is a variety of re-vegetation plants (mix cropping)~~, the age difference between research locations, especially on the criteria > 5 years and the chemical properties of the soil, i.e., pH ($H_20$), Base Saturation and Cation Exchange Capacity. The lower silt fraction and organic matter content of reclamation soils were ~~less~~ infertile (Ezeokoli~~,~~ et~~.~~ al. 2020).

The plant~~/stand~~ diameter growth curve is a mathematical model of a curve that describes the growth of plants~~/trees in terms of the developmental aspect of the diameter dimensions of the trees~~ in the stand, starting from ~~growing,~~ being planted to reaching maturity (Riyanto and Pamungkas~~,~~ 2010)

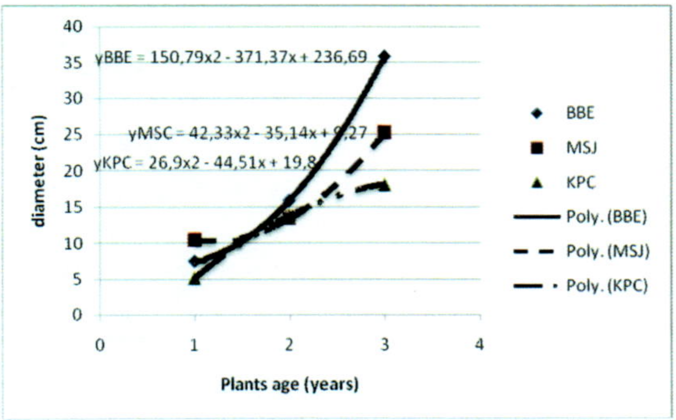
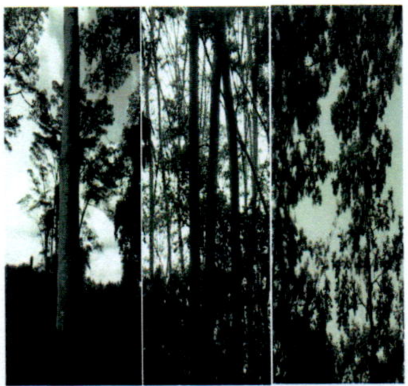



**Figure 4**. Growth of ~~Sengon~~ sengon (BBE, MSJ and KPC) aged > 5 years.

~~Based on~~ **Figure 5**~~, it can be seen~~ shows that the revegetation plant has a growth trend in line with increasing age and ~~is~~ the largest is in the PT. BBE ~~while in the area of PT. MSJ and PT~~. The KPC trend declines after the age of 8 years. The amount of leaf biomass of vegetation increased until the age of 7 years and decreased after ~~the age of~~ 9 years. ~~, while~~In contrast, ~~Sungkai~~ sungkai ~~stands~~ increased at the age of 4 years and decreased after ~~the age of~~ more than 5 years (Murtinah and Komara, 2019). In general~~;~~ (Adman, et.al. 2020), all species observed ~~has~~ have slow growth in ~~term of~~ height and diameters in the first year after planting. ~~and~~ In the following years, there was an acceleration in both ~~high~~ height and diameter growth at various rates.



(a) (b) (c)

**Figure 5**. Growth of ~~Sengon~~ sengon at BBE (a), MSJ (b) and KPC (c) aged > 5 years.

.**Volume** ~~($m^3$/ha)~~

The ~~fast or slow~~ growth rate of a stand is the result of genetic, environmental, and management techniques (Ellok, 2015). The ~~results of the diversity~~ analysis results showed that the differences in vegetation age, soil thickness and their interactions caused significant differences in the volume of trees ~~planted~~ in the land reclamation area of BBE. In contrast, ~~while~~ in the area of MSJ and KPC ~~is very significant~~ only ~~in~~ the age difference of the vegetation had significant effect on the volume of trees.

The average of the highest volume ~~achieved by vegetation planted on~~was found V3 treatment in land reclamation area of BBE (479.69 $m^3$/ha), followed by MSJ (284.82 $m^3$/ha) and PT. KPC (128.37 $m^3$/ha). The difference in the calculated volume of vegetation ~~is~~ was not only caused by the different number of trees aged > 5 years (V3) ~~between~~ among the three

**Commented [A14]:** There was no diversity analysis.

~~different~~ locations, which ~~is~~ was quite significant, but it ~~is~~ was also due to differences in ages of plant and ~~,~~ soil ~~morphology, soil physic and soil fertility~~properties in the reclamation area of each company's mining area.

**Table 4.** Volume ($m^3$/ha) ~~based on~~at different plant ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | |
| PT.BBE | V1 | 12.11±6.90 | 25.21±5.69 | 13.43±3.78 | 16.11 (c) |
| | V2 | 119.53±4.50 | 70.44±8.23 | 101.36±21.2 | 97.11 (b) |
| | V3 | 495.23±44.56 | 289.62±35.69 | 654.22±36.0 | 479.69(a) |
| Average | | 208.96 (a) | 128.42 (c) | 256.34(b) | |
| PT.MSJ | V1 | 13.63±3.17 | 13.45±2.86 | 22.29±5.66 | 16.46 (c) |
| | V2 | 133.75±65.88 | 63.43±18.57 | 127.77±44.1 | 108.31 (b) |
| | V3 | 260.20±12.12 | 205.79±98.9 | 388.47±40.5 | 284.82 (a) |
| Average | | 135.86 | 94.22 | 179.51 | |
| PT. KPC | V1 | 1.37±0.06 | 2.10±0.32 | 3.09±0.41 | 2.19 (c) |
| | V2 | 47.80±15.4 | 43.41±14.9 | 23.94±6.29 | 38.38 (b) |
| | V3 | 181.40±29.5 | 91.37±7.98 | 112.35±29.2 | 128.37 (a) |
| Average | | 76.86 | 45.63 | 46.46 | |

Numbers followed by the same letter in the same column ~~indicate~~ are not significantly different in the LSD test of 0.05.

Low Volume ($m^3$/ha) in PT. KPC ~~is~~ was caused by ~~a different cropping system, namely using~~ mixed cropping, while at the location of PT. BBE and PT. MSJ ~~uses~~ only single species was planted~~monoculture~~. In order to obtain uniformity, then ~~try to use~~ only the plant height and stem diameter of ~~Sengon~~sengon/plot was used for calculation~~only with the assumption that the number of plants used is living mixed plants/plots, then the volume/ha. PT. KPC is caused by a different cropping system (Cropping pattern). In order to obtain uniformity, then try to use plant height and stem diameter of Sengon/plot only with the assumption that the number of plants used is mixed plant life/plot, so Volume/ha is obtained~~ **(Table 4)**.

The average volume ($m^3$/ha) of ~~Sengon~~ *sengon* ~~plants~~ in the area of KPC ~~is~~ was generally lower, except for V3 which ~~is~~ was around 128.37 $m^3$/ha.

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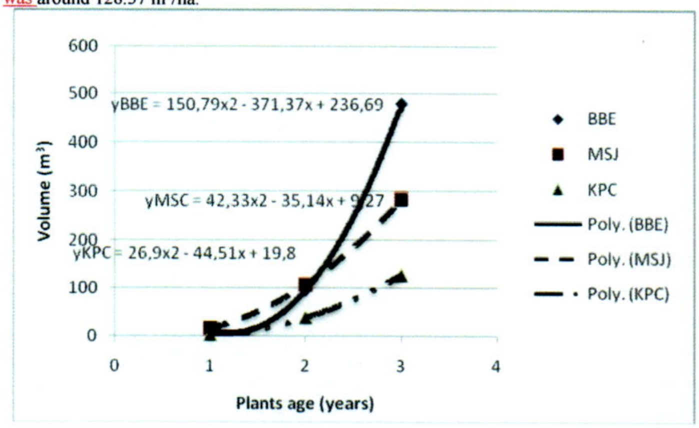


**Figure 6**. Relationship between Volume (m3/ha) and age in Mining and Non-Mining areas.

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The high volume ($m^3$/ha) ~~is~~ was due to low sampling plant used as the basis for calculation of the height and trunk diameter (~~amounts to~~ only about 3-7 stems of plants/plot), resulting in the disproportionate average value of height and large diameter stem ~~disproportionate~~.

*Sengon*~~*Paraserianthes falcataria*~~ litter (liter fall) contributes nutrients to the soil, i.e., ~~in the form of~~ C, N, P about 429 kg/ha, 973 kg/ha and 794 kg/ha per year (Sudomo and Widiyanto~~,~~ 2017)~~. and nutrient content~~ The largest macro-nutrient in ~~*Paraserianthes falcataria*~~*sengon* stands was Calcium (0.28 %), Nitrogen (0.23 %), Potassium (0.19 %), Phosphorus (0.08%) and the lowest was Magnesium at around 145.52 ppm (Herwanto~~,~~ et al. 2016).

The low soil fertility in the PT.KPC land reclamation area was due to the sulfate solution ~~identified~~ found around plot V2. The shallower pyrite ~~has a significant effect on decreasing~~significantly decreased soil pH and increased ~~ing~~ Al and ~~tends to~~ relatively decrease K, Ca, Mg, Cu and Zn (Sutandi, et.al. 2011).

**Figure 7**. Dissolved sulfate ($FeSO_4$) in the V3 border plot of KPC.

**Mean Annual Increment (MAI)**

The annual mean increment (MAI) is the quotient between total production and stand age (Ruchaemi, 2013). The stand potential calculation was~~is~~ done by calculating the volume based on the volume table. Riyanto and Pamungkas, (2010) states that the results of the stand volume calculation are needed to determine the standing stock of each age class, then from the standing stock calculation results, the stand volume increment is calculated in one cycle. This volume increment can be divided into an annual average increment (MAI) and a current average increment (CAI).

**Table 6.** Mean Annual Increment (MAI) at different ~~based on~~ plant ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 | K2 | K3 | |
| PT.BBE | V1 | 8.90±5.07 | 12.16±2.74 | 6.38±1.79 | 7.66 |
| | V2 | 24.12±0.90 | 13.94±1.62 | 19.79±4.14 | 19.28 |
| | V3 | 33.50±3.03 | 19.26±2.39 | 44.05±2.41 | 32.27 |
| Average | | 22.17 | 15.12 | 23.41 | |
| PT.MSJ | V1 | 46.57±1.53 | 6.45±1.37 | 10.48±2.66 | 7.83 |
| | V2 | 23.19±11.46 | 14.67±4.30 | 26.02±9.00 | 21.29 |
| | V3 | 29.24±1.37 | 22.95±11.17 | 45.80±4.54 | 32.66 |
| Average | | 19.67 | 14.69 | 27.43 | |
| PT. KPC | V1 | 0.93±0.04 | 1.37±0.21 | 1.85±0.24 | 1.38 |
| | V2 | 10.175±3.29 | 9.3±3.22 | 5.76±1.51 | 8.41 |
| | V3 | 24.59±4.02 | 14.47±1.26 | 18.24±4.76 | 19.1 |
| Average | | 11.90 | 8.38 | 8.62 | |

~~From the table above, it can be seen~~Table 6 shows that MAI increased with age at each research location, but the largest occurred in the MSJ, ~~then~~ followed by BBE and ~~followed by~~ KPC. Research ~~resulted~~ by Patiun et .al. (2011) in Zulkarnain et.al. (2014), showed that until the reclamation age of 15 years with acacia vegetation, the soil permeability ~~is~~ was still low, i.e., ~~i.e.~~ 12.03 cm/hours at 0 - 15 cm depth and 2,49 cm/hours at 15 - 30 cm depth. This indicates that the change in soil compaction affected the soil permeability up to 15 years age of reclamation.

Various experiences and best practice in the implementation of post-mining reclamation show that degraded ex-mining land ~~is not impossible to~~might become ~~make~~ productive again (Pratiwi, et. al. 2021); The success of post-mining reclamation in restoring tropical forest cover can also support the conservation of biodiversity through the provision of animal habitats that lead to or approach their natural condition. In conclusion, this study found that the diameter and height of *sengon* increased with the increasing age, but the number of surviving trees declined. In contrast, soil thickness had no siginifcant effect on the *sengon* growth

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~~**CONCLUSION**~~

~~Statistical tests showed that the number of live plants was not significantly different (MSJ), was very significant between the age of less than 2 years and the age of 2-5 years and the age of more than 5 years (BBE) and there was a significant difference between the age of less than 2 years and the age of 2- 5 years and more than 5 years old (KPC). Plant height and stem diameter at the age of less than 2 years with 2-5 years and more than 5 years were significantly different (MSJ0 and very significant (BBE and KPC). The interaction between the thickness of the soil sample and the age difference was not significantly different except in different BBE areas. significantly between the age of less than 2 years with the age of 2-5 years and more than 5. In general, the land reclamation area that was given top soiling gave a better growth response in the height and diameter of the stems until the stands were > 5 years old (BBE and MSJ) although the top soiling was very thin; while the sub plots were without top soiling, the plants were able to live up to 15 years (BBE and 9 years (MSJ) during the study, although the number of live plants growing in diameter was relatively lower than the average value.~~

## ACKNOWLEDGEMENTS

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# [biodiv] Editor Decision

From: Smujo Editors (smujo.id@gmail.com)

To: mulyadi_srm@yahoo.com

Date: Tuesday, January 25, 2022 at 12:14 PM GMT+8

mulyadi mulyadi:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "The growth of sengon (Paraserianthes falcataria) at reclamation site of post coal mining area in east Kalimantan".

Our decision is: Revisions Required

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Reviewer A:

Notes on The growth of sengon (Paraserianthes falcataria) at three different plant ages and soil thickness on reclamation site of post coal mining area in East Kalimantan, Indonesia

General comment: This article was poorly written, so major revision has been done.

Comments were also made directly on the text.

TITLE:

Some editing was done in the title.

ABSTRACT

The Abstract has been revised considerably because the original one was poorly written.

INTRODUCTION

1. There are many redundancies and some irrelevant information; these redundancies and irrelevant information have been deleted.
2. Lines 59-51: According to the Minister of Forestry Regulation No. P.64/Menhut-II/2014 IUPPHK-RE restoration activities are carried out to restore biological elements (flora and fauna) and non-biological elements (soil, climate and topography) in an area to their original species, so that achieve biological balance and its ecosystem (Nining, et.al. 2017),...

There is no need to quote Nining et al. 2917; quote the Permenhut directly.

Like the Abstract, the introduction has been revised considerably.

MATERIALS AND METHODS

1. The methods were not written systematically. They have been revised, but some additions should be done, i.e., the formulas to calculate MAI and CAI should be given.

RESULTS AND DISCUSSION

1. Lines 161-163: The equations and curves are shown in **Figure 2** below:

**Figure 2**. Relationship between number of live plants (stems/plot).

Figure was not found.

1. Lines 170-172: The increase in the age class of land cover "did not change the soil fertility" value, but there was an increase in the values of pH, BS, C-organic, N-total, P-available and K-available until the age of 8 years, while C-organic and N-total were still continues to increase until the age of > 10 years (Wahyuni, 2013).

This statement is contradictory. The soil fertility did not change, but there were increases in pH and essential elements.

CONCLUSION

The Conclusion is too long. It has been reduced to two sentences integrated in the discussion.

Recommendation: Revisions Required

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Biodiversitas Journal of Biological Diversity

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# [biodiv] Editor Decision

From: Smujo Editors (smujo.id@gmail.com)

To: mulyadi_srm@yahoo.com

Date: Wednesday, March 16, 2022 at 08:44 PM GMT+8

mulyadi mulyadi:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "The growth of sengon (Paraserianthes falcataria) at reclamation site of post coal mining area in east Kalimantan".

Our decision is: Revisions Required

------------------------------------------------------

Reviewer A:

Notes:

I made little editing on this article as follows:

Line 60-61: I added a relevant reference to support the statement of this article in lines 58-59: When the sites have been successfully revegetated with fast-growing species, economically more valuable trees (e.g., from the family Dipterocarpaceae) should be planted based on scientific studies.

Line 62: I made a little grammatical correction.

I made the word "sengon" in italic font because it is not an English word.

Line 137: I deleted the letter a.

Line 147: I corrected the misspelling of the word "amendment".

Line 178: I corrected the misspelling of the word "diameter.'

Lines 195-196: I edited the sentence.

Line 212: I made the word "sungkai" italic.

Line 225: I added the word "in".

Line 236: I made the word "sengon" italic.

Line 251: I changed the word "decrease" to "decreased".

The style of references has not followed the guide from Biodiversitas and should be edited.

Recommendation: Revisions Required

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A-edited with track of changes mulyadi article 9672-Article Text.docx
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# The growth of sengon (*Paraserianthes falcataria*) at three different plant ages and soil thickness classes on reclamation sites of post coal mining areas in East Kalimantan, Indonesia

MULYADI [1], DADDY RUHIYAT[2], MARLON IVANHOE AIPASSA[3], SIGIT HARDWINANTO[4]

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Manuscript received: .......(Date of abstract/manuscript submission). Revision accepted: ......

**Abstract.** Mulyadi, Ruhiyat D, Aipassa M, Hardwinanto S. 2021. The growth of *sengon* (*Paraserianthes Falcataria*) at three different plant ages and soil thicknesses on reclamation site of post-mining area in East Kalimantan. *Sengon* (*Paraserianthes falcataria*) is a fast- growing species commonly used for reclamation of post-coal mining areas in East Kalimantan. The study aimed to determine the impact of different thicknesses of topsoil applied at some reclamation sites after coal mining activities on the growth of *sengon* . Three coal mining companies were chosen as study areas, i.e., PT Bukit Baiduri Energi (BBE), PT. Mahakam Sumber Jaya (MSJ), and PT. Kaltim Prima Coal (KPC). The regolith soil layer at the reclamation site had three thickness classes (0-10 cm, 0-30 cm, 0-100 cm), and the *sengon* growing on reclamation had three ages, i.e., < 2 yrs old (initial growth phase), 2-5 yrs old (tending phase), and > 5 yrs old (independent growth phase). The number of surviving plants, plant height, and plant stem's diameter were recorded, and the data were analyzed using ANOVA and the least significant difference at 5% level. The results showed that no significant difference in the number of trees among different ages of sengon plantation was found at MSJ. In contrast, at BBE and KPC the number of surviving trees decreased significantly with the increasing plant age. The growth of the plant (height, diameter) increased significantly along with plant age in all sites. The interaction between top soiling thickness factor and plant age factor produced no different result in plant growth except for plant height at BBE. The sengon plants had not been able to lower the surface soil density in the land reclamation area.

Key words: Pioneer vegetation, growth, mine, soil thickness, overburden, fertility, reclamation

**Running title:** Growth of Sengon (*paraserianthes falcataria*) at reclamation site

## INTRODUCTION

Almost all coal mining operations in forest concession areas in East Kalimantan caused significant forest ecosystem disturbance. Therefore, management of post-mining forest lands must be conducted thoroughly, consisting of land reshaping , topsoil spreading, mining waste treatment, soil erosion-sedimentation control, and land revegetation. These three aspects should be evaluated to assess whether the ecosystem recovery is successful or not based on the performance of land reclamation, soil erosion-sedimentation land revegetation (planted areas, growth percentage, plant species, the composition of fast-growing and long-lived species, plant health), the diversity of fungi and bacteria (Sudarmaji et al. 2021).

The natural forests have a closed nutrient cycle, and the nutrients are accumulated mainly in the forest tree biomass. If the trees are cut and the topsoil is removed, the composition of symbiotic microbes will change, so the host and the symbiotic fungi will be disconnected. Mycorrhizal fungi can only survive on the exposed forest floor in the spores, mycelial hyphae, or other propagules under limited conditions. If there is an increase in temperature on the forest floor coupled with the entry of ultraviolet light, the fungal population will decrease drastically and disappear. Mycorrhiza is a biological agent that could improve the soil fertility (Daras et al. 2015) .

Coal mining in East Kalimantan use openpit mining techniques, which should be conducted carefully due to the changes of landform, the damage of soil structure, the lack of topsoil, the change of topsoil properties, the decrease of biodiversity, and the declined of emvironmental quality (Subowo 2011).

The steps in mining activities include land clearing, stripping topsoil and subsoil to the parent material layer (regolith), then stripping the bedrock to the surface of the coal seam. These steps are carried out by digging bench, removing and burying the cover layer through backfilling to each mining block, and adjusting to the mineral deposit deployment (Zulkarnain et al. 2014).

The openpit mining system caused extraordinary changes in the ecosystem in the mining area, namely the loss of natural vegetation, the opening of land (soil, source rock, and bedrock were peeled and removed), and the fauna that live in these habitats will move to a more suitable place or die (Boer 2008). These open areas must be rehabilitated immediately with fast-growing species so that the area/environment can return to its original condition.

According to the Minister of Forestry Regulation No. P.64/Menhut-II/2014 IUPPHK-RE restoration activities are carried out to restore biological elements (flora and fauna) and non-biological elements (soil, climate, and topography) in an area to their original species to achieve ecological balance .

Selection and management of pioneer plants for reclamation of degraded land are some of the keys to reclamation success (Hapsari et al. 2020). As pioneer plants, Leguminosae, such as sengon, may grow quickly and adapt to poor soil conditions with low nutrients.

In general (Pratiwi et al. 2021), the forestation process is initiated by selecting plants resistant to drought or fast-growing fodder crops that can grow with limited nutrients.The rapid closure of vegetation is important in controlling site stabilization, runoff, and erosion. When the sites have been successfully revegetated with fast-growing species, economically more valuable trees (e.g., from the family Dipterocarpaceae) should be planted based on scientific studies. Three species of Dipterocarpaceae have been planted successfully on coal mined land that had been planted previously with a legume, i.e., *Samanea saman* (Wiryono et al. 2016).

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The objectives of this study ~~were~~ was to compare the growth of *sengon* at three different plant ages and soil thicknesses on three reclamation sites of BBE, MSJ, and KPC. The results of this study may become inputs and technical references to coal mining operations management for a successful reclamation program on a post-coal mined landscape.

## MATERIALS AND METHODS

### Study area

The study area was located in Kutai Kartanegara Regency of East Kalimantan Province, Indonesia. The species and age of plants studied were determined based on the results of the preliminary survey. The study of *sengon* growth was conducted in three reclaimed post-coal mining sites with three different plant ages and soil thickness classes: (I) BBE sites, geographically positioned at E 117° 04' 06" S 0° 26' 58" (< 2 years old), E 117° 04' 44" S 0° 26' 13" ( 2-5 years old) and E 117° 05' 02" S 0° 26' 40" (> 5 years old) , (ii) MSJ sites, E 117° 12' 53" S 0° 13' 21" (< 2 years old), E 117° 13' 46" S 0° 12' 38" ( 2-5 years old) and E 117° 08' 12" S 0° 17' 42" (> 5 years old) , and KPC sites, E 117° 36' 15" S 0° 48' 37" (< 2 years old), E 117° 35' 05" S 0° 49' 02" ( 2-5 years old) and E 117° 34' 59" S 0° 50' 55" (> 5 years old). The sample plot area was 400 $m^2$ (20 m x 20 m). In each sample plot, the number of living plants, plant height and stem diameter were recorded.

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### Experimental design

Randomized Complete Block Design (RCBD) was used with a split plot design. The main plot is the growth and productivity of crops were vegetation (V) by plant ages < 2 (V1), 2-5 years (V2) and > 5 years (V3). Sub-plot is the thickness of the surface soil (K) consisting of 3 (three) levels, namely the thickness of the surface soil < 10 cm (S1), the thickness between 0 – 30 cm (S2) and the thickness > 30 cm (S3).

### Soil analysis

Soil Sample (0- 10 cm, 0-30 cm and > 30 cm thick) in each sample plot were taken for analysis in soil laboratory, Faculty of agriculture, Mulawarman University, Samarinda, East Kalimantan. Soil acidity (pH $H_20$ and KCl) was measured with electrometry pH meters; C organic content with Walkley-Black method; total-N with Kjedahl method, P and K with North Carolina method; Exchangeable base Cations ($Ca^{++}$, $Mg^{++}$, $Na^+$, $K^+$) were determined with extraction method with ammonium acetate; Texture with pipet method, and Bulk Density with Gravimetry.

### Vegetation data Analysis

The growth of plants, the Mean annual increment (MAI) and the Current annual Increment (CAI) were calculated. The following formula was used to calculate MAI was = $Y^{(t)}/t$ Where = $Y^{(t)}$ = Yield of time t

The Increase in main-stem volume pf wood per unit of area of forest in the current years (as $m^3 Ha^{-1}$ ) a measure of forest productivity. The formula to calculate CAI was = MAI x plants age.

The number of live plants from stems/plot was converted to stem/ha (N/ha), then analyzed using a formula based on the regression equation, Anova (analysis of variance) was performed to determine the difference in growth of plant, Mean annual increment (MAI) and Current annual Increment (CAI) among sites. It was followed by Least Significant Difference (LSD) test at 5% level.

## RESULTS AND DISCUSSION

**Number of living *sengon***

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According to the Minister of Forestry Regulation Number: P.60/Menhut-II/2009 concerning Guidelines for assessment of the Success of Forest Reclamation, revegetation activities are categorized as successful if the percentage of healthy plants is more than 80% .

### NUMBER OF LIVING PLANTS/ (*SENGON*)

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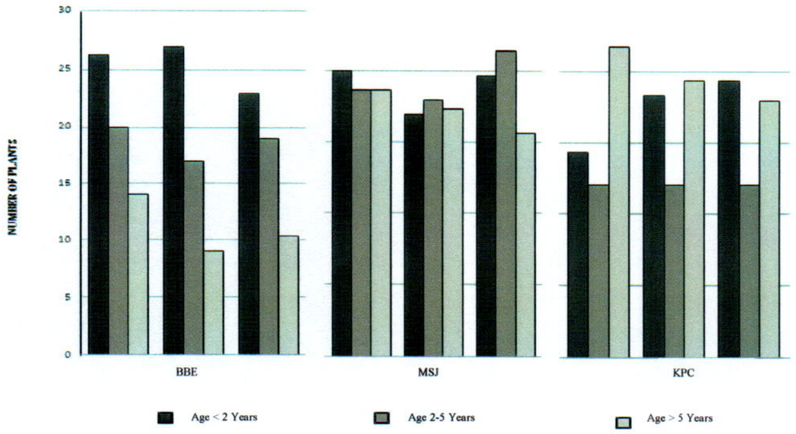



**Figure 1**. Plant number at different ages of stand (stem/plot)

**Table 1**. Average number of living plants (stems/plot) on different plant ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average | N/ha % |
|---|---|---|---|---|---|---|
| | | K1(SE) | K2 (SE) | K3 (SE) | | |
| PT.BBE | V1 | 26.33±1.25 | 27,00±2.17 | 23.00±3.50 | 25.44 (a) | 57.29 |
| | V2 | 20.00±1.50 | 17,00±1.00 | 19.00±1.32 | 18.67 (b) | 42.05 |
| | V3 | 14.00±1.00 | 9.00±0.50 | 10.33±0.76 | 11.11 (c) | 25.02 |
| Average | | 20.11 | 17.67 | 17.44 | | |
| PT.MSJ | V1 | 20.00±0.86 | 17,00±0.50 | 19.67±1.04 | 18.89 | 42.54 |
| | V2 | 18.67±3.17 | 18.00±1.50 | 21.33±2.46 | 19.33 | 43.53 |
| | V3 | 18.67±1.60 | 17.33±1.25 | 15.67±3.21 | 17.22 | 38.78 |
| Average | | 19.11 | 17.44 | 18.89 | | |
| PT. KPC | V1 | 14.33±1.25 | 18.33±0.28 | 19.33±0.76 | 17.33 (b) | 62.98 |
| | V2 | 12.00±1.00 | 12.00±1.32 | 12.00±0.76 | 12.00 (b) | 44.22 |
| | V3 | 21.67±0.76 | 19.33±2.02 | 18.00±3.04 | 19.67 (a) | 78.00 |
| Average | | 16.00 | 16.56 | 16.44 | | |

Numbers followed by the same letter in the same column are not significantly different in the 0.05 LSD test.

The average percentage of living plants/ha decreased with the increasing ages of vegetation: in the BBE area, they were 57.29% (V1), 42.05% (V2), and 25.02% (V3), respectively. Relatively, and in the MSJ they were 42.54% (V1), 43.35% (V2), and 38.78% (V3). However, a different pattern was found in the KPC area, i.e., 62.98%, 44.22 and 78% (V3). Because the average percentage of living plants/ha was lower than 80%, the stability of soil aggregates was low. The soil structure of all soil reclamation profiles is determined by the type and structure of the soil-forming material layers (Khaidir et al. 2018).

The aggregate of topsoil and subsoil taken with heavy equipment can be destroyed and the soil is easily damaged and eroded by rain water, especially on sloping land. As a result, soil organic matter will be eroded, and the soil becomes compact. Movement of water and air affects the chemical and biological processes in the soil (Nadila and Pulunggono 2019).

The higher bulk density in undisturbed soils can be attributed to compaction from the use of heavy machinery during the replacement of soils in mined-out areas and a higher fraction of clay in reclamations soil (Ezeokoli et al. 2020).

The average soil bulk density values in reclamation area less than 2 years old a was 1.48 gr/cm$^3$ at BBE, 1.44 gr/ cm$^3$ at MSJ and 1.49 gr/ cm$^3$ KPC), and relatively lower at 10 cm soil thick, i.e., 1.45 gr/ cm$^3$ BBE, 1.29 gr/ cm$^3$ MSJ and 1.44 gr/ cm$^3$ KPC), but this value is still considered high. The bulk density at the same site decreases with the increasing age of land reclamation due to the growth of root system and the addition of biomass. In the 15 to 20 years old post-coal mining land reclamation, the vegetation can rebuild soil structure, decrease bulk density and improve soil porosity (Noviyanto et al. 2017).

The productivity of mine soils without soil amendement is mainly limited in by low nutrient availability (Anonim, 2019); Therefore, basic mineral NPK-fertilization before planting is essential. The correlation between number of living plants and ages of vegetation (V1, V2, and V3) and the equations are shown in Figure 2.

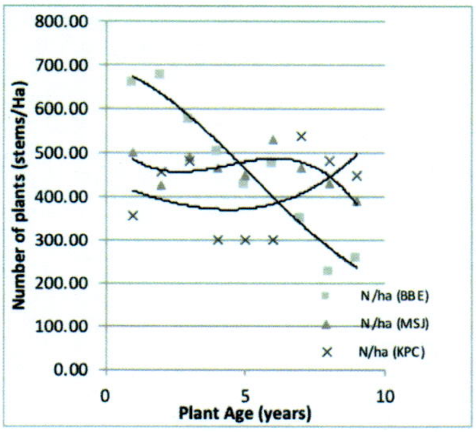



**Figure 2**. Relationship between number of living plants (stems/plot) and ages.

**Plant height**

The average height of revegetation plants at different ages (V1, V2 and V3) in the land reclamation area of BBE, MSJ and KPC was tested in relation in the thickness of the soil. The results of the analysis showed that the different ages of the vegetation caused a very significant difference to the mean height, while the thickness of the soil did not cause any difference.

Although the nutrients status did not change, there were increases in the values of pH, Base Saturation, organic-C, total-N, available-P and available-K until the age of 8 years, while the organic-C and total-N continued to increase until the age of > 10 years (Wahyuni, 2013).

**Table 2**. Plant height (m) at different plant ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | Average |
| PT.BBE | V1 | 6.10±1.37 | 8.50±0.91 | 7.44±0.69 | 7.35 (c) |
| | V2 | 15.49±0.63 | 13.59±0.59 | 14.45±1.20 | 14.51 (b) |
| | V3 | 24.53±1.18 | 25.63±2.18 | 27.35±1.13 | 25.84 (a) |
| Average | | 17.60 | 19.24 | 19.75 | |
| PT.MSJ | V1 | 5.26±0.41 | 5.44±0.38 | 5.89±0.41 | 5.53 (b) |
| | V2 | 19.99±1.16 | 18.8±1.84 | 20.11±1.47 | 19.66 (a) |
| | V3 | 21.26±0.75 | 21.26±1.76 | 22.89±0.67 | 21.80 (a) |
| Average | | 478 | 436 | 472 | |
| PT. KPC | V1 | 3.08±0.15 | 3.80±0.29 | 3.31±0.23 | 3.40 (c) |
| | V2 | 11.82±1.66 | 11.18±1.48 | 9.09±0.67 | 10.70 (b) |
| | V3 | 15.60±1.15 | 13.15±0.70 | 13.20±1.27 | 13.99 (a) |
| Average | | 10.21 | 9.32 | 8.59 | |

Numbers followed by the same letter in the same column are not significantly different in the 0.05 LSD test.

Plant height is influenced by genetic characters and environmental factors, such as close plant spacing which will provide higher growth due to less solar radiation. The growth rate of a stand is the result of genetic, environmental and management techniques (Ellok, 2015).

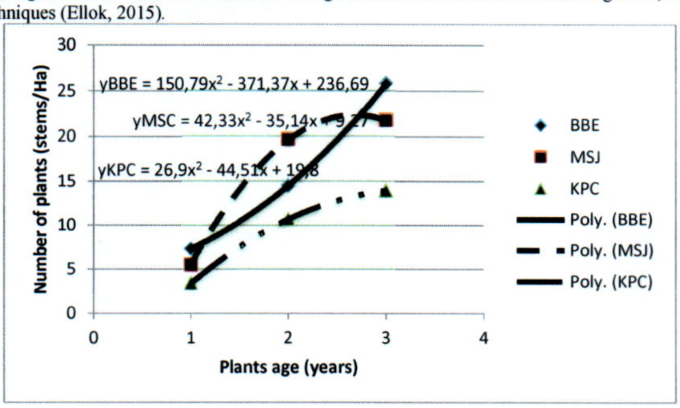



**Figure 3.** Relationship between plant height (cm) and age

The average heights of plants in the area of KPC were 3.40 m (V1), 10.70 m (V2) and 13.99 m (V3), lower than those in the area of MSJ (5.53 m/V1, 19.66 m/V2 and 21.80 m/V3) and in the area of BBE (7.35 m/V1, 14.51 (V2) and 25.84/V3).

The growth curve from the regression analysis in the reclamation of mining areas was relatively flat after >4 years of age, except in the BBE mining area because the vegetation age of the research plot observed in the BBE area (as determined by the Company) was older than other areas. Therefore, the data on plant diameter/height is larger with the equation as shown in **Figure 3**.

With increasing age, trees will increase in height, the diameter of the canopy circle and the unit mass of the tree. The diamaeter growth ofbroadleaf trees in the tropics occurs through all year seasons. The culmination point of the diameter increment in age-old stands was reached more quickly than the increment in height (Ruchaemi 2013).

The average trunk diameter in the area BBE and KPC was significantly different among age classes, while in the area of MSJ the average trunk diameter in V1 and V2 was not different but significantly different from V3.

The results of further tests with 5% LSD in the BBE area showed that the largest diameter was in V3 (35.85 cm) at 15 years old, in the MSJ (25.35 cm) at 9 years old, and KPC (18.13 cm) at 7 years old. This result is in accordance with general growth pattern; namely the highest tree diameter growth occurs when it has reached a diameter of 30-40 cm, then decreases gradually with increasing tree diameter (Wahyudi and Anwar 2013).

**Table 3**. Plant stem diameter (cm) at different ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | |
| PT.BBE | V1 | 19.92±4.20 | 27.55±2.12 | 23.11±1.20 | 7.50 (c) |
| | V2 | 52.80±0.14 | 46.48±0.58 | 50.85±3.77 | 15.94 (b) |
| | V3 | 110.18±7.98 | 97.99±5.86 | 129.48±5.30 | 35.85 (a) |
| Average | | 19.42 | 18.27 | 21.60 | |
| PT.MSJ | V1 | 29.91±2.49 | 31.60±3.12 | 36.03±2.68 | 10.36 (b) |
| | V2 | 44.79±10.90 | 37.33±9.06 | 44.24±10.31 | 13.41 (a) |
| | V3 | 68.94±1.63 | 77.98±3.43 | 90.77±8.36 | 25.33 (a) |
| Average | | 15.25 | 15.60 | 18.16 | |
| PT. KPC | V1 | 15.01±0.54 | 14.57±0.60 | 18.49±0.80 | 5.10 (c) |
| | V2 | 46.41±7.14 | 44.59±3.93 | 38.93±1.98 | 13.79 (b) |
| | V3 | 61.40±4.03 | 51.66±3.49 | 57.75±5.50 | 18.13 (a) |
| Average | | 13.04 | 11.76 | 12.22 | |

Numbers followed by the same letter in the same column are not significantly different in the LSD 0.05 test.

Like plant height, stem diameter growth is also affected by mixed-species planting in the area of KPC, the age difference between research locations, especially on the criteria > 5 years and the chemical properties of the soil, i.e., pH ($H_20$), Base Saturation and Cation Exchange Capacity. The lower silt fraction and organic matter content of reclamation soils were infertile (Ezeokoli et al. 2020).

Physico- chemical soil properties of reclamation were important for plant growth such as shown in ~~table~~ Table 4 ~~below~~. The bulk density was relatively ~~stable~~ similar, but ~~more increase the value~~slightly higher at different plant ages (BBE and KPC) caused different sources of material overburden.

**Table 4**. Physico-chemical propertie of mined areas

| Location | | pH | Org. Matter | N-tot. | CEC | BS | $P_2O_5$ | BD |
|---|---|---|---|---|---|---|---|---|
| | | | % | % | Cmol (+)/kg | % | ppm | 90/cm$^3$ |
| BBE | V1 | 5.81 | 1.69 | 0.10 | 17.03 | 70.89 | 2.56 | 1.48 |
| | V2 | 4.05 | 1.33 | 0.12 | 18.37 | 21.78 | 2.30 | 1.53 |
| | V3 | 5.82 | 4.28 | 0.18 | 27.36 | 55.44 | 3.20 | 1.50 |
| MSJ | V1 | 5.24 | 1.97 | 0.10 | 13.43 | 49.22 | 3.18 | 1.44 |
| | V2 | 5.61 | 1.54 | 0.12 | 14.12 | 43.44 | 4.64 | 1.36 |
| | V3 | 5.40 | 0.86 | 0.10 | 16.11 | 52.0 | 4.39 | 1.35 |
| KPC | V1 | 3.74 | 2.48 | 0.09 | 9.55 | 17.56 | 3.33 | 1.49 |
| | V2 | 3.97 | 2.32 | 0.12 | 10.23 | 41.89 | 7.62 | 1.52 |
| | V3 | 4.09 | 2.82 | 0.11 | 11.15 | 28.11 | 3.75 | 1.55 |

The plant diameter growth curve is a mathematical model of a curve that describes the growth of plants in the stand, starting from being planted to reaching maturity (Riyanto and Pamungkas 2010)

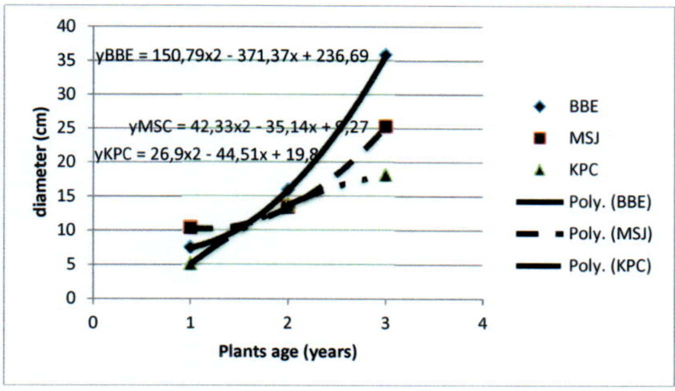
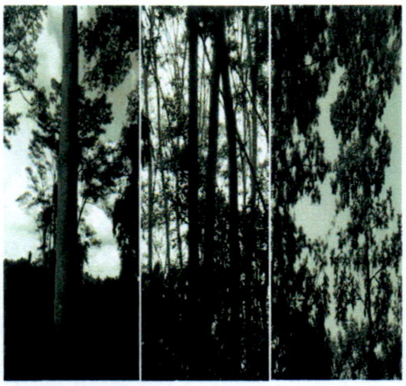



**Figure 4**. Growth of sengon (BBE, MSJ and KPC) aged > 5 years.

**Figure 5** shows that the revegetation plant has a growth trend in line with increasing age and the largest is in the PT. BBE. The KPC trend declines after the age of 8 years. The amount of leaf biomass of vegetation increased until the age of 7 years and decreased after 9 years. In contrast, *sungkai* increased at the age of 4 years and decreased after more than 5 years (Murtinah and Komara, 2019). In general (Adman, et.al. 2020), all species observed have slow growth in height and diameter in the first year after planting. In the following years, there was an acceleration in both height and diameter growth at various rates.



(A) (B) (C)

**Figure 5**. Growth of *sengon* at BBE (a), MSJ (b) and KPC (c) aged > 5 years.

**Volume**

The growth rate of a stand is the result of genetic, environmental, and management techniques (Ellok, 2015). The analysis results showed that the differences in vegetation age, soil thickness and their interactions caused significant differences in the volume of trees in the land reclamation area of BBE. In contrast, in the area of MSJ and KPC only the age difference of the vegetation had significant effect on the volume of trees.

The average of the highest volume was found in V3 treatment in land reclamation area of BBE (479.69 $m^3$/ha), followed by MSJ (284.82 $m^3$/ha) and KPC (128.37 $m^3$/ha). The difference in the calculated volume of vegetation was not only caused by the different number of trees aged > 5 years (V3) among the three locations, which was quite significant, but it was also due to differences in ages of plant and soil properties in the reclamation area of each company's mining area.

**Table 5.** Volume ($m^3$/ha) at different plant ages (V) and soil thicknesses (K).

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | |
| PT.BBE | V1 | 12.11±6.90 | 25.21±5.69 | 13.43±3.78 | 16.11 (c) |
| | V2 | 119.53±4.50 | 70.44±8.23 | 101.36±21.2 | 97.11 (b) |
| | V3 | 495.23±44.56 | 289.62±35.69 | 654.22±36.0 | 479.69(a) |
| Average | | 208.96 (a) | 128.42 (c) | 256.34(b) | |
| PT.MSJ | V1 | 13.63±3.17 | 13.45±2.86 | 22.29±5.66 | 16.46 (c) |
| | V2 | 133.75±65.88 | 63.43±18.57 | 127.77±44.1 | 108.31 (b) |
| | V3 | 260.20±12.12 | 205.79±98.9 | 388.47±40.5 | 284.82 (a) |
| Average | | 135.86 | 94.22 | 179.51 | |
| PT. KPC | V1 | 1.37±0.06 | 2.10±0.32 | 3.09±0.41 | 2.19 (c) |
| | V2 | 47.80±15.4 | 43.41±14.9 | 23.94±6.29 | 38.38 (b) |
| | V3 | 181.40±29.5 | 91.37±7.98 | 112.35±29.2 | 128.37 (a) |
| Average | | 76.86 | 45.63 | 46.46 | |

Numbers followed by the same letter in the same column are not significantly different in the LSD test of 0.05.

Low Volume ($m^3$/ha) in KPC was caused by mixed cropping, while at the location of BBE and MSJ only single species was planted. In order to obtain uniformity, then only the plant height and stem diameter of *sengon*/plot was used for calculation **(Table 4)**.

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The average volume ($m^3$/ha) of *sengon* in the area of KPC was generally lower, except for V3 which was around 128.37 $m^3$/ha.

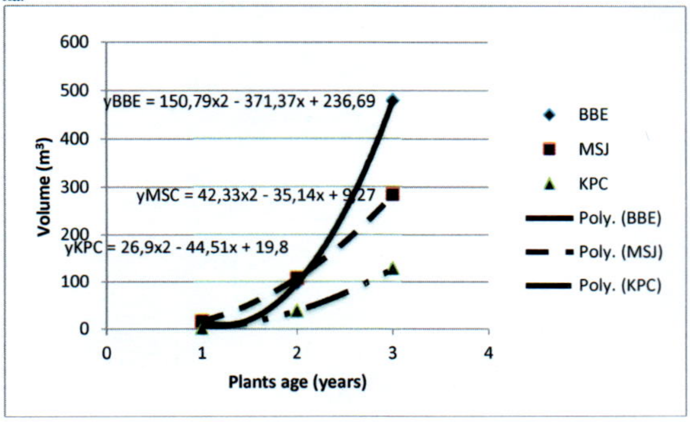


**Figure 6**. Relationship between Volume (m3/ha) and age

The high volume ($m^3$/ha) was due to low sampling plant used as the basis for calculation of the height and trunk diameter (only about 3-7 stems of plants/plot), resulting in the disproportionate average value of height and large diameter stem.

*Sengon* litter (liter fall) contributes nutrients to the soil, i.e., C, N, P about 4291 kg/ha, 973 kg/ha and 794 kg/ha per year (Sudomo and Widiyanto 2017). The largest macronutrient in *sengon* stands was Calcium (0.28 %), Nitrogen (0.23 %), Potassium (0.19 %), Phosphorus (0.08%) and the lowest was Magnesium at around 145.52 ppm (Herwanto et al. 2016).

The low soil fertility in the KPC land reclamation area was due to the sulfate solution found around plot V2. The shallower pyrite significantly decreased soil pH and increased Al and relatively decreased K, Ca, Mg, Cu and Zn (Sutandi, et.al. 2011).

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## ACKNOWLEDGEMENTS

I would like to express my deep and sincere gratitude to the Director General of Higher Education Ministry of Education and Culture of the Republic of Indonesia that a part of this work is funded. I am very much thankful to Mr. Ir. Immanuel Manege (GM PT. Kaltim Prima Coal), Ir. Boorliant Satryana (HSE Manager of PT. Mahakam Sumber Jaya) and Akbar Maulana, S.Si (PT. Bukit Baiduri Energi) who have provided the opportunity to conduct research in the company's land reclamation area.

Dear Authors,

The manuscript shows an interesting study about the growth of Sengon at reclamation sites of post coal mining area.

However, this study is still not clear and convincing overall. I suggest some improvements before to be published. You can find my comments through the text listed here.

1. English needs professional revision throughout manuscript.
2. Title section perhaps should be improved by including soil thickness and plant age.
3. Abstract section should be improved, please provide short introduction, method, data analysis, results, and conclusion.
4. You can add more keywords which not written in your title.
5. Introduction section should be improved, please follow the proper instruction from this journal about citation way, add more relevant references as your background study.
6. Material and methods section should be improved, please provide data analysis that you perform in to analyze your data, I suppose you performed a one-way or two-way ANOVA with least significant different (LSD) as the post-hoc test, instead of BNT because BNT is the term used in Indonesian. Please state clearly how long you conduct this experiment. Please organize/ order your paragraph properly. Please put data analysis at the end of your method section. Please divide your method into several sub-section for example: study site, experimental design, data collection, data analysis.
7. Results and discussion section should be improved, please provide the standard error (SE) as the proper way showing ANOVA results or you may provide your results in bar plot including the error bar and letters to indicate the differences.
    a. In Figure 1, what is N/Plot? Do you mean Individual/Plot?
    b. What is the meaning of number 1-9 in the X-axis?
    c. What is the meaning of number of plants in the Y-axis? Do you mean number of species or number of individuals? I suggest this figure should be improved.
    d. What kind of relationship analysis you used for Figure 2, 3, 5, and 6?
    e. Please state clearly factor and level in each table instead you abbreviate them using single letter (V and K).
    f. What is the different between Rod diameter and Stem diameter?
    g. Figure 4 should be labeled as (a), (b), and (c).
    h. Calculation for MAI dan CAI should be provided in methods.
    i. The discussion is hard to be understood, please improve due to lack of English,
8. All citation throughout manuscript should be revised.
9. Please follow the journal style for references.

You may have a look some references related to tree growthbelow:

https://smujo.id/biodiv/article/view/3399

https://smujo.id/biodiv/article/view/8642

https://smujo.id/biodiv/article/view/2017

mulyadi mulyadi:

We have reached a decision regarding your submission to Biodiversitas Journal of Biological Diversity, "The growth of sengon (Paraserianthes falcataria) at reclamation site of post coal mining area in east Kalimantan".

Our decision is: Revisions Required

------------------------------------------------------

Reviewer A:

Notes on The growth of sengon (Paraserianthes falcataria) at three different plant ages and soil thickness on reclamation site of post coal mining area in East Kalimantan, Indonesia

General comment: This article was poorly written, so major revision has been done.

Comments were also made directly on the text.

TITLE:

Some editing was done in the title.

ABSTRACT

The Abstract has been revised considerably because the original one was poorly written.

INTRODUCTION

1. There are many redundancies and some irrelevant information; these redundancies and irrelevant information have been deleted.
2. Lines 59-51: According to the Minister of Forestry Regulation No. P.64/Menhut-II/2014 IUPPHK-RE restoration activities are carried out to restore biological elements (flora and fauna) and non-biological

elements (soil, climate and topography) in an area to their original species, so that achieve biological balance and its ecosystem (Nining, et.al. 2017),...

There is no need to quote Nining et al. 2917; quote the Permenhut directly.

Like the Abstract, the introduction has been revised considerably.

MATERIALS AND METHODS

1. The methods were not written systematically. They have been revised, but some additions should be done, i.e., the formulas to calculate MAI and CAI should be given.

RESULTS AND DISCUSSION

1. Lines 161-163: The equations and curves are shown in **Figure 2** below:

**Figure 2**. Relationship between number of live plants (stems/plot).

Figure was not found.

1. Lines 170-172: The increase in the age class of land cover "did not change the soil fertility" value, but there was an increase in the values of pH, BS, C-organic, N-total, P-available and K-available until the age of 8 years, while C-organic and N-total were still continues to increase until the age of > 10 years (Wahyuni, 2013).

This statement is contradictory. The soil fertility did not change, but there were increases in pH and essential elements.

CONCLUSION

The Conclusion is too long. It has been reduced to two sentences integrated in the discussion.

Recommendation: Revisions Required

-----------------------------------------------------

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------------------------------------------------------

Reviewer A:

Notes:

I made little editing on this article as follows:

Line 60-61: I added a relevant reference to support the statement of this article in lines 58-59: When the sites have been successfully revegetated with fast-growing species, economically more valuable trees (e.g., from the family Dipterocarpaceae) should be planted based on scientific studies.

Line 62: I made a little grammatical correction.

I made the word “sengon” in italic font because it is not an English word.

Line 137: I deleted the letter a.

Line 147: I corrected the misspelling of the word “amendment”.

Line 178: I corrected the misspelling of the word “diameter.’

Lines 195-196: I edited the sentence.

Line 212: I made the word “sungkai” italic.

Line 225: I added the word “in”.

Line 236: I made the word “sengon” italic.

Line 251: I changed the word “decrease” to “decreased”.

The style of references has not followed the guide from Biodiversitas and should be edited.

Recommendation: Revisions Required

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mulyadi mulyadi:

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Our decision is: Revisions Required

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Reviewer C:

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9. What is the meaning of number 1-9 in the X-axis?
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11. What kind of relationship analysis you used for Figure 2, 3, 5, and 6?
12. Please state clearly factor and level in each table instead you abbreviate them using single letter (V and K).
13. What is the different between Rod diameter and Stem diameter?
14. Figure 4 should be labeled as (a), (b), and (c).
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Recommendation: Revisions Required

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**BIODIVERSITAS**
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# The growth of *Paraserianthes falcataria* at three different plant ages and soil thickness classes on reclamation sites of post-coal mining areas in East Kalimantan, Indonesia

**MULYADI[1,♥], DADDY RUHIYAT[2], MARLON IVANHOE AIPASSA[2], SIGIT HARDWINANTO[2]**
[1]Faculty of Agriculture, Universitas Mulawarman. Jl. Pasir Balengkong No.1, Kampus Gunung Kelua, Samarinda 75123, East Kalimantan, Indonesia. Tel./fax.: +62-541-749159/738341, ♥email: mulyadi_srm@yahoo.com
[2]Faculty of Forestry, Universitas Mulawarman. Jl. Penajam, Kampus Gunung Kelua, Samarinda 75123, East Kalimantan, Indonesia

Manuscript received: 21 October 2021. Revision accepted: 22 March 2022.

**Abstract.** *Mulyadi, Ruhiyat D, Aipassa MI, Hardwinanto S. 2022. The growth of* Paraserianthes falcataria *at three different plant ages and soil thickness classes on reclamation sites of post-coal mining areas in East Kalimantan, Indonesia. Biodiversitas 23: 1930-1937.* Sengon (*Paraserianthes falcataria* (L.) Nielsen syn. *Falcataria moluccana* (Miq.) Barneby & J.W. Grimes) is a fast-growing species commonly used for reclamation of post-coal mining areas in East Kalimantan. The study aimed to determine the impact of different thicknesses of topsoil applied at some reclamation sites after coal mining activities on the growth of *P. falcataria*. Three coal mining companies were chosen as study areas, i.e., PT Bukit Baiduri Energi (BBE), PT. Mahakam Sumber Jaya (MSJ), and PT. Kaltim Prima Coal (KPC). The regolith soil layer at the reclamation site had three thickness classes (0-10 cm, 0-30 cm, 0-100 cm), and the *P. falcataria* growing on reclamation had three ages, i.e.,< 2 yrs old (initial growth phase), 2-5 yrs old (tending phase), and > 5 yrs old (independent growth phase). The number of surviving plants, plant height, and plant stem's diameter were recorded, and the data were analyzed using ANOVA and the least significant difference at 5% level. The results showed that no significant difference in the number of trees among different ages of *P. falcataria* plantation was found at MSJ. In contrast, at BBE and KPC the number of surviving trees decreased significantly with the increasing plant age. The growth of the plant (height, diameter) increased significantly along with plant age in all sites. The interaction between the top soiling thickness factor and plant age factor produced no different result in plant growth except for plant height at BBE. The *P. falcataria* plants had not been able to lower the surface soil density in the land reclamation area.

**Keywords:** Fertility, growth, mine, overburden, pioneer vegetation, reclamation, soil thickness

## INTRODUCTION

Almost all coal mining operations in forest concession areas in East Kalimantan caused significant forest ecosystem disturbance. The damage is because the topsoil was discharged and was replaced by the formerly buried materials (Wiryono et al. 2016). Therefore, management of post-mining forest lands must be conducted thoroughly, consisting of land reshaping, topsoil spreading, mining waste treatment, soil erosion-sedimentation control, and land revegetation. These three aspects should be evaluated to assess whether the ecosystem recovery is successful or not based on the performance of land reclamation, soil erosion-sedimentation land revegetation (planted areas, growth percentage, plant species, the composition of fast-growing and long-lived species, plant health), the diversity of fungi and bacteria (Sudarmadji and Hartati 2021).

The natural forests have a closed nutrient cycle, and the nutrients are accumulated mainly in the forest tree biomass. If the trees are cut and the topsoil is removed, the composition of symbiotic microbes will change, so the host and the symbiotic fungi will be disconnected. Mycorrhizal fungi can only survive on the exposed forest floor in the spores, mycelial hyphae, or other propagules under limited conditions. If there is an increase in temperature on the forest floor coupled with the entry of ultraviolet light, the fungal population will decrease drastically and disappear. Mycorrhiza is a biological agent that could improve soil fertility (Daras et al. 2015).

Coal mining in East Kalimantan uses open-pit mining techniques, which should be conducted carefully due to the changes of landform, the damage of soil structure, the lack of topsoil, the change of topsoil properties, the decrease of biodiversity, and the decline of environmental quality (Subowo 2011).

The steps in mining activities include land clearing, stripping topsoil and subsoil to the parent material layer (regolith), then stripping the bedrock to the surface of the coal seam. These steps are carried out by digging the bench, removing and burying the cover layer through backfilling to each mining block, and adjusting to the mineral deposit deployment (Zulkarnain et al. 2014).

The open-pit mining system caused extraordinary changes in the ecosystem in the mining area, namely the loss of natural vegetation, the opening of land (soil, source rock, and bedrock were peeled and removed), and the fauna that live in these habitats will move to a more suitable place or die (Boer 2008). These open areas must be rehabilitated immediately with fast-growing species so that the area/environment can return to its original condition.

According to the Minister of Forestry Regulation No. P.64/Menhut-II/2014 IUPPHK-RE restoration activities are carried out to restore biological elements (flora and fauna) and non-biological elements (soil, climate, and topography) in an area to their original species to achieve ecological balance.

Selection and management of pioneer plants for reclamation of degraded land are some of the keys to reclamation success (Hapsari et al. 2020). As pioneer plants, Leguminosae, such as sengon (*Paraserianthes falcataria* (L.) Nielsen syn. *Falcataria moluccana* (Miq.) Barneby & J.W. Grimes), may grow quickly and adapt to poor soil conditions with low nutrients.

In general, the forestation process is initiated by selecting plants resistant to drought or fast-growing fodder crops that can grow with limited nutrients. The rapid closure of vegetation is important in controlling site stabilization, runoff, and erosion. When the sites have been successfully revegetated with fast-growing species, economically more valuable trees (e.g., from the family Dipterocarpaceae) should be planted based on scientific studies. Three species of Dipterocarpaceae have been planted successfully on coal mined land that had been planted previously with a legume, i.e., *Samanea saman* (Wiryono et al. 2016).

The objective of this study was to compare the growth of *P. falcataria* at three different plant ages and soil thicknesses on three reclamation sites of BBE, MSJ, and KPC. The results of this study may become inputs and technical references to coal mining operations management for a successful reclamation program on a post-coal mined landscape.

## MATERIALS AND METHODS

### Study area

The study area was located in Kutai Kartanegara Regency of East Kalimantan Province, Indonesia. The species and age of plants studied were determined based on the results of the preliminary survey. The study of *P. falcataria* growth was conducted in three reclaimed post-coal mining sites with three different plant ages and soil thickness classes: (I) BBE sites, geographically positioned at E 117° 04' 06" S 0° 26' 58" (< 2 years old), E 117° 04' 44" S 0° 26' 13" ( 2-5 years old) and E 117° 05' 02" S 0° 26' 40" (> 5 years old) , (ii) MSJ sites, E 117° 12' 53" S 0° 13' 21" (< 2 years old), E 117° 13' 46" S 0° 12' 38" ( 2-5 years old) and E 117° 08' 12" S 0° 17' 42" (> 5 years old) , and KPC sites, E 117° 36' 15" S 0° 48' 37" (< 2 years old), E 117° 35' 05" S 0° 49' 02" ( 2-5 years old) and E 117° 34' 59" S 0° 50' 55" (> 5 years old). The sample plot area was 400 $m^2$(20 m x 20 m). In each sample plot, the number of living plants, plant height and stem diameter were recorded.

### Experimental design

Randomized Complete Block Design (RCBD) was used with a split-plot design. The main plot is the growth and productivity of crops were vegetation (V) by plant ages<2 (V1), 2-5 years (V2) and > 5 years (V3). Sub-plot is the thickness of the surface soil (K) consisting of 3 (three) levels, namely the thickness of the surface soil < 10 cm (S1), the thickness between 0-30 cm (S2) and the thickness > 30 cm (S3).

### Soil analysis

Soil samples (0-10 cm, 0-30 cm and > 30 cm thick) in each sample plot were taken for analysis in soil laboratory, Faculty of Agriculture, Universitas Mulawarman, Samarinda, East Kalimantan, Indonesia. Soil acidity (pH $H_20$ and KCl) was measured with electrometry pH meters; C organic content with Walkley-Black method; total-N with Kjeldahl method, P and K with North Carolina method; Exchangeable base Cations ($Ca^{++}$, $Mg^{++}$, $Na^+$, $K^+$) were determined with extraction method with ammonium acetate; Texture with pipet method and Bulk Density with Gravimetry.

### Vegetation data analysis

The growth of plants, the Mean annual increment (MAI) and the Current annual Increment (CAI) were calculated. The following formula was used to calculate MAI was = $Y^{(t)}/t$ Where = $Y^{(t)}$ = Yield of time t

The Increase in main-stem volume pf wood per unit of forest area in the current years (as $m^3Ha^{-1}$) is a measure of forest productivity. The formula to calculate CAI was = MAI x plants age.

The number of live plants from stems/plot was converted to stem/ha (N/ha), then analyzed using a formula based on the regression equation.

ANOVA (analysis of variance) was performed to determine the difference in the growth of plant, Mean annual increment (MAI) and Current annual Increment (CAI) among sites. It was followed by Least Significant Difference (LSD) test at the 5% level.

## RESULTS AND DISCUSSION

### Number of living *Paraserianthes falcataria*

According to the Minister of Forestry Regulation Number: P.60/Menhut-II/2009 concerning Guidelines for assessment of the Success of Forest Reclamation, revegetation activities are categorized as successful if the percentage of healthy plants is more than 80%.

The average percentage of living plants/ha decreased with the increasing ages of vegetation: in the BBE area, they were 57.29% (V1), 42.05% (V2), and 25.02% (V3), respectively. Relatively, and in the MSJ, they were 42.54% (V1), 43.35% (V2), and 38.78% (V3). However, a different pattern was found in the KPC area, i.e., 62.98%, 44.22 and 78% (V3). Because the average percentage of living plants/ha was lower than 80%, the stability of soil aggregates was low. The soil structure of all soil reclamation profiles is determined by the type and structure of the soil-forming material layers (Khaidir et al. 2018).

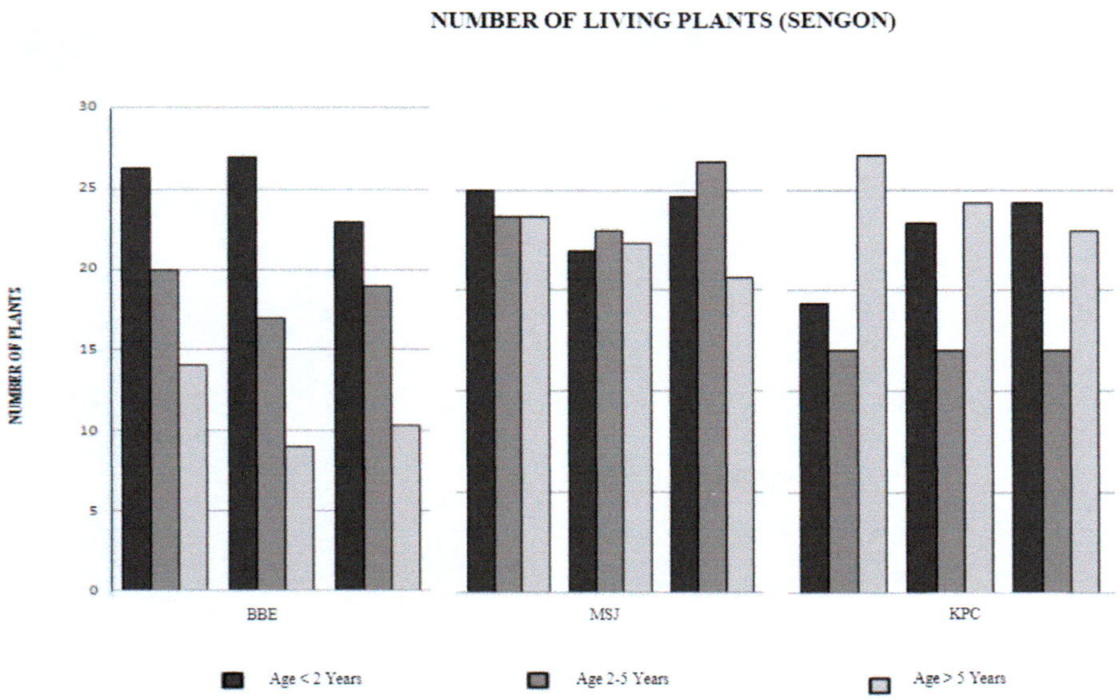


**Figure 1.** Plant number at different ages of stand (stem/plot)

**Table 1.** The average number of living plants (stems/plot) on different plant ages (V) and soil thicknesses (K)

| | V Factor | K Factor | | | Average | N/ha % |
|---|---|---|---|---|---|---|
| | | K1(SE) | K2 (SE) | K3 (SE) | | |
| PT.BBE | V1 | 26.33±1.25 | 27,00±2.17 | 23.00±3.50 | 25.44 (a) | 57.29 |
| | V2 | 20.00±1.50 | 17,00±1.00 | 19.00±1.32 | 18.67 (b) | 42.05 |
| | V3 | 14.00±1.00 | 9.00±0.50 | 10.33±0.76 | 11.11 (c) | 25.02 |
| Average | | 20.11 | 17.67 | 17.44 | | |
| PT.MSJ | V1 | 20.00±0.86 | 17,00±0.50 | 19.67±1.04 | 18.89 | 42.54 |
| | V2 | 18.67±3.17 | 18.00±1.50 | 21.33±2.46 | 19.33 | 43.53 |
| | V3 | 18.67±1.60 | 17.33±1.25 | 15.67±3.21 | 17.22 | 38.78 |
| Average | | 19.11 | 17.44 | 18.89 | | |
| PT. KPC | V1 | 14.33±1.25 | 18.33±0.28 | 19.33±0.76 | 17.33 (b) | 62.98 |
| | V2 | 12.00±1.00 | 12.00±1.32 | 12.00±0.76 | 12.00 (b) | 44.22 |
| | V3 | 21.67±0.76 | 19.33±2.02 | 18.00±3.04 | 19.67 (a) | 78.00 |
| Average | | 16.00 | 16.56 | 16.44 | | |

Numbers followed by the same letter in the same column are not significantly different in the 0.05 LSD test

The aggregate of topsoil and subsoil were taken with heavy equipment can be destroyed and the soil is easily damaged and eroded by rainwater, especially on sloping land. As a result, soil organic matter will be eroded, and the soil becomes compact. The movement of water and air affects the chemical and biological processes in the soil (Nadila and Pulunggono 2019).

The higher bulk density in undisturbed soils can be attributed to compaction from the use of heavy machinery during the replacement of soils in mined-out areas and a higher fraction of clay in reclamations soil (Ezeokoli et al. 2020).

The average soil bulk density values in reclamation area less than 2 years old was 1.48 gr/cm$^3$ at BBE, 1.44gr/cm$^3$ at MSJ and 1.49 gr/cm$^3$ KPC), and relatively lower at 10 cm soil thick, i.e., 1.45 gr/cm$^3$ BBE, 1.29 gr/cm$^3$ MSJ and 1.44 gr/cm$^3$ KPC), but this value is still considered high. The bulk density at the same site decreases with the increasing age of land reclamation due to the growth of the root system and the addition of biomass. In the 15 to 20 years old post-coal mining land reclamation, the vegetation can rebuild soil structure, decrease bulk density and improve soil porosity (Noviyanto et al. 2017).

The productivity of mine soils without soil amendment is mainly limited by low nutrient availability (Anonim 2019); Therefore, basic mineral NPK-fertilization before planting is essential. The correlation between the number of living plants and ages of vegetation (V1, V2, and V3) and the equations are shown in Figure 2.

**Table 2.** Plant height (m) at different plant ages (V) and soil thicknesses (K)

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | |
| PT.BBE | V1 | 6.10±1.37 | 8.50±0.91 | 7.44±0.69 | 7.35 (c) |
| | V2 | 15.49±0.63 | 13.59±0.59 | 14.45±1.20 | 14.51 (b) |
| | V3 | 24.53±1.18 | 25.63±2.18 | 27.35±1.13 | 25.84 (a) |
| Average | | 17.60 | 19.24 | 19.75 | |
| PT.MSJ | V1 | 5.26±0.41 | 5.44±0.38 | 5.89±0.41 | 5.53 (b) |
| | V2 | 19.99±1.16 | 18.8±1.84 | 20.11±1.47 | 19.66 (a) |
| | V3 | 21.26±0.75 | 21.26±1.76 | 22.89±0.67 | 21.80 (a) |
| Average | | 478 | 436 | 472 | |
| PT. KPC | V1 | 3.08±0.15 | 3.80±0.29 | 3.31±0.23 | 3.40 (c) |
| | V2 | 11.82±1.66 | 11.18±1.48 | 9.09±0.67 | 10.70 (b) |
| | V3 | 15.60±1.15 | 13.15±0.70 | 13.20±1.27 | 13.99 (a) |
| Average | | 10.21 | 9.32 | 8.59 | |

Numbers followed by the same letter in the same column are not significantly different in the 0.05 LSD test

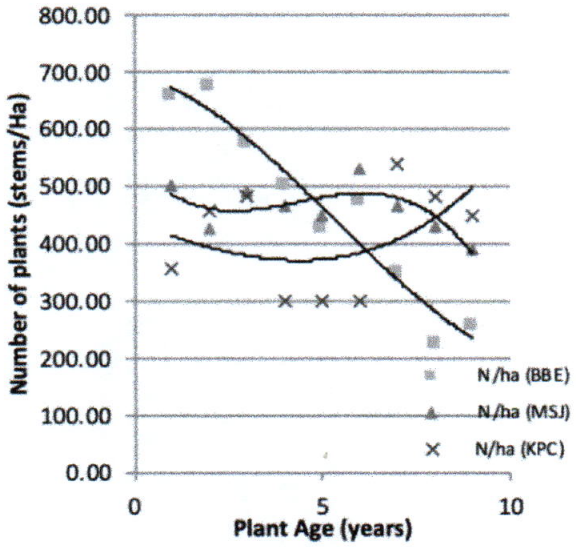


**Figure 2.** Relationship between number of living plants (stems/plot) and ages

**Plant height**

The average height of revegetation plants at different ages (V1, V2 and V3) in the land reclamation area of BBE, MSJ and KPC was tested in relation to the thickness of the soil. The results of the analysis showed that the different ages of the vegetation caused a very significant difference to the mean height, while the thickness of the soil did not cause any difference.

Although the nutrients status did not change, there were increases in the values of pH, Base Saturation, organic-C, total-N, available-P and available-K until the age of 8 years, while the organic-C and total-N continued to increase until the age of > 10 years (Wahyuni 2013).

Plant height is influenced by genetic characteristics and environmental factors, such as close plant spacing, providing higher growth due to less solar radiation. The growth rate of a stand is the result of genetic, environmental and management techniques (Ellok 2015).

The average heights of plants in the area of KPC were 3.40 m (V1), 10.70 m (V2) and 13.99 m (V3), lower than those in the area of MSJ (5.53 m/V1, 19.66 m/V2 and 21.80 m/V3) and in the area of BBE (7.35 m/V1, 14.51 (V2) and 25.84/V3).

The growth curve from the regression analysis in the reclamation of mining areas was relatively flat after >4 years of age, except in the BBE mining area because the vegetation age of the research plot observed in the BBE area (as determined by the Company) was older than other areas. Therefore, the data on plant diameter/height is larger with the equation as shown in Figure 3.

With increasing age, trees will increase in height, the diameter of the canopy circle and the unit mass of the tree. The diameter growth of broadleaf trees in the tropics occurs through all year seasons. The culmination point of the diameter increment in age-old stands was reached more quickly than the increment in height (Ruchaemi 2013).

The average trunk diameter in the area BBE and KPC were significantly different among age classes, while in the area of MSJ the average trunk diameter in V1 and V2 was not different but significantly different from V3.

The results of further tests with 5% LSD in the BBE area showed that the largest diameter was in V3 (35.85 cm) at 15 years old, in the MSJ (25.35 cm) at nine years old, and KPC (18.13 cm) at seven years old. This result is in accordance with the general growth pattern; namely, the highest tree diameter growth occurs when it has reached a diameter of 30-40 cm, then decreases gradually with increasing tree diameter (Wahyudi and Anwar 2013).

Like plant height, stem diameter growth is also affected by mixed-species planting in the area of KPC, the age difference between research locations, especially on the criteria > 5 years and the chemical properties of the soil, i.e., pH ($H_20$), Base Saturation and Cation Exchange Capacity. The lower silt fraction and organic matter content of reclamation soils were infertile (Ezeokoli et al. 2020).

Physico-chemical soil properties of reclamation were important for plant growth, as shown in Table 4. The bulk density was relatively similar, but slightly higher at different plant ages (BBE and KPC), causing different sources of material overburden.

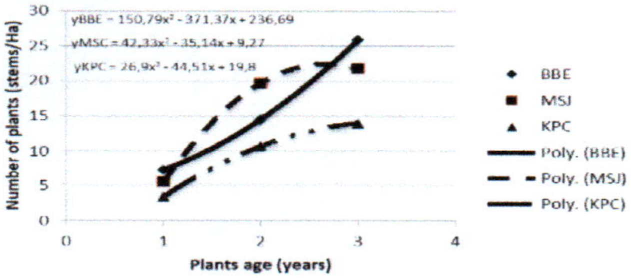


Figure 3. Relationship between plant height (cm) and age

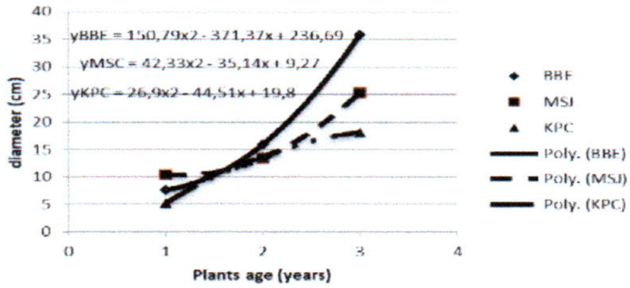


**Figure 4.** Growth of *Paraserianthes falcataria* (BBE, MSJ and KPC) aged > 5 years

**Table 3.** Plant stem diameter (cm) at different ages (V) and soil thicknesses (K)

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | |
| PT.BBE | V1 | 19.92±4.20 | 27.55±2.12 | 23.11±1.20 | 7.50 (c) |
| | V2 | 52.80±0.14 | 46.48±0.58 | 50.85±3.77 | 15.94 (b) |
| | V3 | 110.18±7.98 | 97.99±5.86 | 129.48±5.30 | 35.85 (a) |
| Average | | 19.42 | 18.27 | 21.60 | |
| PT.MSJ | V1 | 29.91±2.49 | 31.60±3.12 | 36.03±2.68 | 10.36 (b) |
| | V2 | 44.79±10.90 | 37.33±9.06 | 44.24±10.31 | 13.41 (a) |
| | V3 | 68.94±1.63 | 77.98±3.43 | 90.77±8.36 | 25.33 (a) |
| Average | | 15.25 | 15.60 | 18.16 | |
| PT. KPC | V1 | 15.01±0.54 | 14.57±0.60 | 18.49±0.80 | 5.10 (c) |
| | V2 | 46.41±7.14 | 44.59±3.93 | 38.93±1.98 | 13.79 (b) |
| | V3 | 61.40±4.03 | 51.66±3.49 | 57.75±5.50 | 18.13 (a) |
| Average | | 13.04 | 11.76 | 12.22 | |

Numbers followed by the same letter in the same column are not significantly different in the LSD 0.05 test

**Table 4**. Physico-chemical properties of mined areas

| Location | | pH | Org. Matter | N-tot. | CEC | BS | $P_2O_5$ | BD |
|---|---|---|---|---|---|---|---|---|
| | | | % | % | Cmol (+)/kg | % | ppm | 90/cm³ |
| | V1 | 5.81 | 1.69 | 0.10 | 17.03 | 70.89 | 2.56 | 1.48 |
| | V2 | 4.05 | 1.33 | 0.12 | 18.37 | 21.78 | 2.30 | 1.53 |
| | V3 | 5.82 | 4.28 | 0.18 | 27.36 | 55.44 | 3.20 | 1.50 |
| MSJ | V1 | 5.24 | 1.97 | 0.10 | 13.43 | 49.22 | 3.18 | 1.44 |
| | V2 | 5.61 | 1.54 | 0.12 | 14.12 | 43.44 | 4.64 | 1.36 |
| | V3 | 5.40 | 0.86 | 0.10 | 16.11 | 52.0 | 4.39 | 1.35 |
| KPC | V1 | 3.74 | 2.48 | 0.09 | 9.55 | 17.56 | 3.33 | 1.49 |
| | V2 | 3.97 | 2.32 | 0.12 | 10.23 | 41.89 | 7.62 | 1.52 |
| | V3 | 4.09 | 2.82 | 0.11 | 11.15 | 28.11 | 3.75 | 1.55 |

**Table 5.** Volume (m³/ha) at different plant ages (V) and soil thicknesses (K)

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | |
| PT.BBE | V1 | 12.11±6.90 | 25.21±5.69 | 13.43±3.78 | 16.11 (c) |
| | V2 | 119.53±4.50 | 70.44±8.23 | 101.36±21.2 | 97.11 (b) |
| | V3 | 495.23±44.56 | 289.62±35.69 | 654.22±36.0 | 479.69(a) |
| Average | | 208.96 (a) | 128.42 (c) | 256.34(b) | |
| PT.MSJ | V1 | 13.63±3.17 | 13.45±2.86 | 22.29±5.66 | 16.46 (c) |
| | V2 | 133.75±65.88 | 63.43±18.57 | 127.77±44.1 | 108.31 (b) |
| | V3 | 260.20±12.12 | 205.79±98.9 | 388.47±40.5 | 284.82 (a) |
| Average | | 135.86 | 94.22 | 179.51 | |
| PT. KPC | V1 | 1.37±0.06 | 2.10±0.32 | 3.09±0.41 | 2.19 (c) |
| | V2 | 47.80±15.4 | 43.41±14.9 | 23.94±6.29 | 38.38 (b) |
| | V3 | 181.40±29.5 | 91.37±7.98 | 112.35±29.2 | 128.37 (a) |
| Average | | 76.86 | 45.63 | 46.46 | |

Numbers followed by the same letter in the same column are not significantly different in the LSD test of 0.05

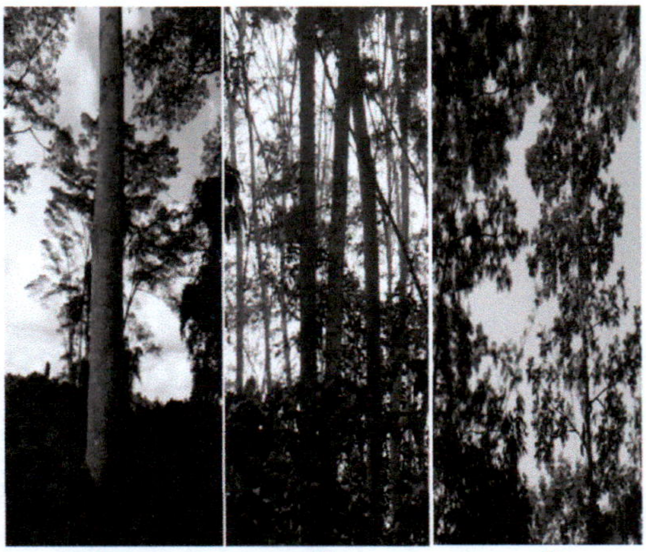


**Figure 5.** Growth of *Paraserianthes falcataria* at BBE (A), MSJ (B) and KPC (C) aged > 5 years

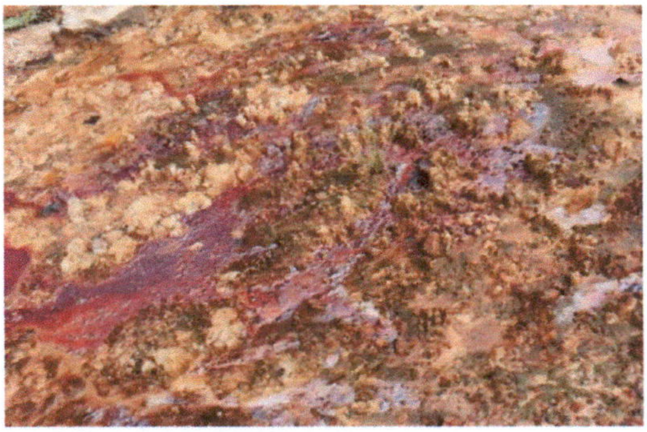

**Figure 7.** Dissolved sulfate ($FeSO_4$) in the V3 border plot of KPC

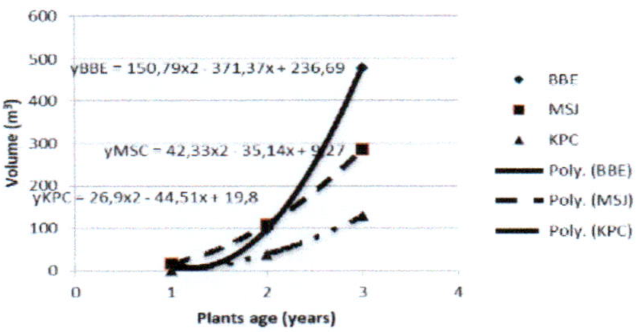


**Figure 6.** Relationship between volume ($m^3$/ha) and age

The plant diameter growth curve is a mathematical model of a curve that describes the growth of plants in the stand, starting from being planted to reaching maturity (Riyanto and Pamungkas 2010).

Figure 5 shows that the revegetation plant has a growth trend in line with increasing age and the largest is in the PT. BBE. The KPC trend declines after the age of eight years. The amount of leaf biomass of vegetation increased until the age of seven years and decreased after nine years. In contrast, sungkai increased at the age of four years and decreased after more than five years (Murtinah and Komara 2019). In general (Adman et al. 2020), all species observed have slow growth in height and diameter in the first year after planting. In the following years, there was an acceleration in both height and diameter growth at various rates.

## Volume

The growth rate of a stand is the result of genetic, environmental, and management techniques (Ellok 2015). The analysis results showed that the differences in vegetation age, soil thickness and their interactions caused significant differences in the volume of trees in the land reclamation area of BBE. In contrast, in the area of MSJ and KPC only the age difference of the vegetation had a significant effect on the volume of trees.

The average of the highest volume was found in V3 treatment in the land reclamation area of BBE (479.69 $m^3$/ha), followed by MSJ (284.82 $m^3$/ha) and KPC (128.37 $m^3$/ha). The difference in the calculated volume of vegetation was not only caused by the different number of trees aged > 5 years (V3) among the three locations, which was quite significant, but it was also due to differences in ages of plant and soil properties in the reclamation area of each company's mining area.

Low Volume ($m^3$/ha) in KPC was caused by mixed cropping, while at the location of BBE and MSJ only single species was planted. In order to obtain uniformity, then only the plant height and stem diameter of *P. falcataria*/plot was used for calculation (Table 4).

The average volume ($m^3$/ha) of *P. falcataria* in the area of KPC was generally lower, except for V3 which was around 128.37 $m^3$/ha.

The high volume ($m^3$/ha) was due to the low sampling plant used as the basis for calculation of the height and trunk diameter (only about 3-7 stems of plants/plot), resulting in the disproportionate average value of height and large diameter stem.

*Paraserianthes falcataria* litter (liter fall) contributes nutrients to the soil, i.e., C, N, P about 4291 kg/ha, 973 kg/ha and 794 kg/ha per year (Sudomo and Widiyanto 2017). The largest macronutrient in *P. falcataria* stands was Calcium (0.28 %), Nitrogen (0.23 %), Potassium (0.19 %), Phosphorus (0.08%) and the lowest was Magnesium at around 145.52 ppm (Herwanto et al. 2016).

The low soil fertility in the KPC land reclamation area was due to the sulfate solution found around plot V2. The shallower pyrite significantly decreased soil pH and increased Al and relatively decreased K, Ca, Mg, Cu and Zn (Sutandi et al. 2011).

**Table 6.** Mean Annual Increment (MAI) at different plant ages (V) and soil thicknesses (K)

| | V Factor | K Factor | | | Average |
|---|---|---|---|---|---|
| | | K1 (SE) | K2 (SE) | K3 (SE) | |
| PT.BBE | V1 | 8.90±5.07 | 12.16±2.74 | 6.38±1.79 | 7.66 |
| | V2 | 24.12±0.90 | 13.94±1.62 | 19.79±4.14 | 19.28 |
| | V3 | 33.50±3.03 | 19.26±2.39 | 44.05±2.41 | 32.27 |
| | Average | 22.17 | 15.12 | 23.41 | |
| PT.MSJ | V1 | 46.57±1.53 | 6.45±1.37 | 10.48±2.66 | 7.83 |
| | V2 | 23.19±11.46 | 14.67±4.30 | 26.02±9.00 | 21.29 |
| | V3 | 29.24±1.37 | 22.95±11.17 | 45.80±4.54 | 32.66 |
| | Average | 19.67 | 14.69 | 27.43 | |
| PT. KPC | V1 | 0.93±0.04 | 1.37±0.21 | 1.85±0.24 | 1.38 |
| | V2 | 10.175±3.29 | 9.3±3.22 | 5.76±1.51 | 8.41 |
| | V3 | 24.59±4.02 | 14.47±1.26 | 18.24±4.76 | 19.1 |
| | Average | 11.90 | 8.38 | 8.62 | |

**Mean Annual Increment (MAI)**

The annual mean increment (MAI) is the quotient between total production and stand age (Ruchaemi 2013). The potential stand calculation was done by calculating the volume based on the volume table. Riyanto and Pamungkas (2010) state that the results of the stand volume calculation are needed to determine the standing stock of each age class, then from the standing stock calculation results, the stand volume increment is calculated in one cycle. This volume increment can be divided into an annual average increment (MAI) and a current average increment (CAI).

Table 6 shows that MAI increased with age at each research location, but the largest occurred in the MSJ, followed by BBE and KPC. Research by Patiung et al. (2011) in Zulkarnain et al. (2014) showed that until the reclamation age of 15 years with acacia vegetation, the soil permeability was still low, i.e., 12.03 cm/hour at 0-15 cm depth and 249 cm/hour at 15-30 cm depth. This indicates that the change in soil compaction affected the soil permeability up to 15 years age of reclamation.

Various experiences and best practices in the implementation of post-mining reclamation show that degraded ex-mining land might become productive again (Pratiwi et al. 2021); The success of post-mining reclamation in restoring tropical forest cover can also support the conservation of biodiversity through the provision of animal habitats that lead to or approach their natural condition. In conclusion, this study found that the diameter and height of *P. falcataria* increased with the increasing age, but the number of surviving trees declined. In contrast, soil thickness had no significant effect on the *P. falcataria* growth.

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