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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

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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 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 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).

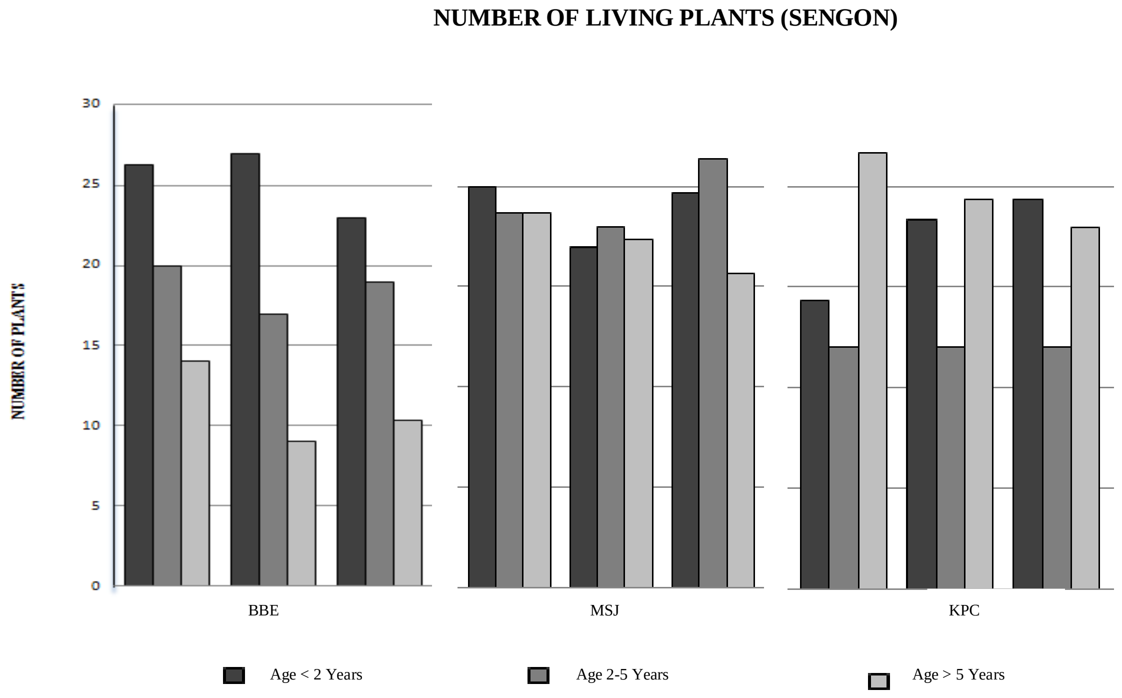

Figure 1. Plant number at different ages of stand (stem/plot)

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

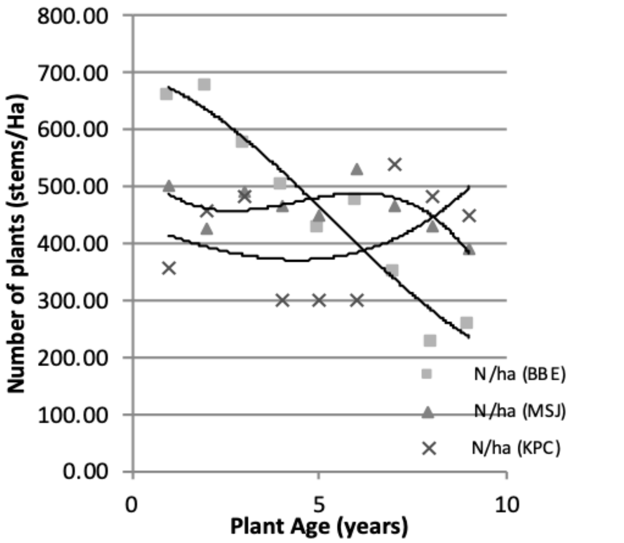

Figure 2. Relationship between number of living plants (stems/plot) and ages

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

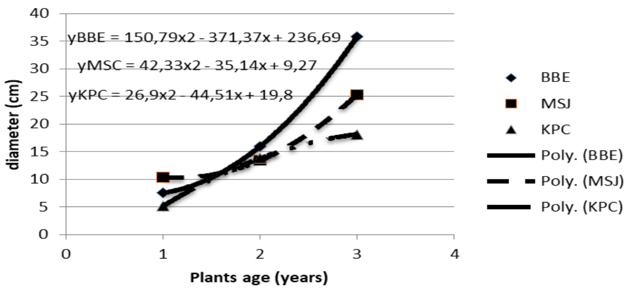

Figure 4. Growth of *Paraserianthes falcataria* (BBE, MSJ and KPC) aged > 5 years

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	$90/cm^3$
	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 (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

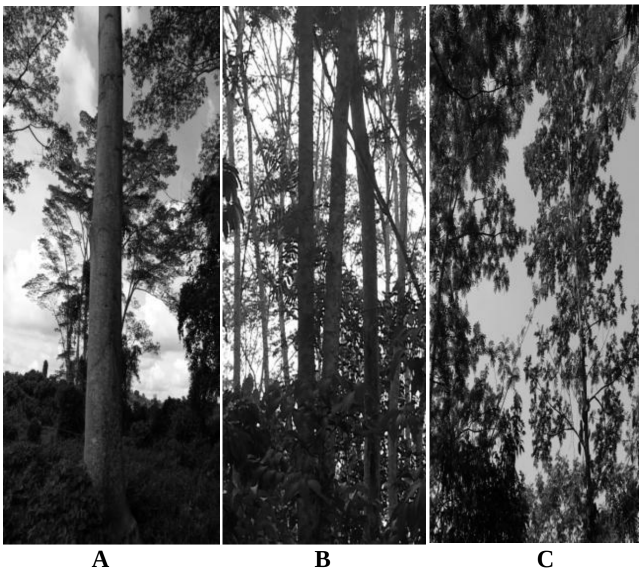

Figure 5. Growth of *Paraserianthes falcataria* at BBE (A), MSJ (B) and KPC (C) aged > 5 years

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

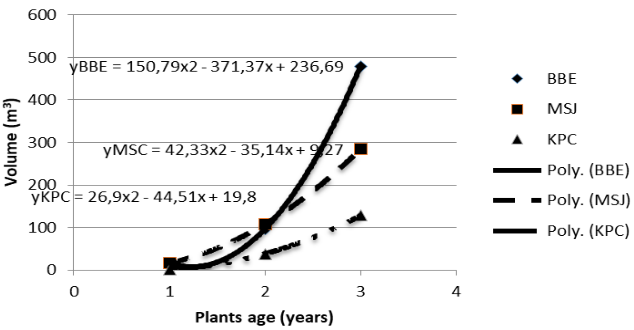

Figure 6. Relationship between volume (m^3/ha) and age

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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