THE GROWTH OF LOCAL TREE SPECIES ON POST-COAL MINING AREAS IN EAST KALIMANTAN

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THE GROWTH OF LOCAL TREE SPECIES ON POST-COAL MINING AREAS IN EAST KALIMANTAN. Post-coal mining areas need rehabilitation to restore its functionality. Not all plants could grow well on bare ex-coal mining area because of the excessive light intensity and extreme temperature fluctuations. This study is aimed to determine suitable local tree species for rehabilitating mined areas. Planting was carried out in November 2012, and observations were made in November 2015. The study site was in the district of Samboja, Kutai Kartanegara, East Kalimantan Province, Indonesia. Research results revealed that seven tree species survived well in the ex-coal mining land, i.e., *Vitex pinnata* L., *Syzygium scortechinii* (Merr.) Merr. & Perry, *Syzygium polyanthum* (Wight) Walp., *Shorea balangeran* (Korth.) Burck, *Macaranga motleyana* (Mull.Arg.) Mull.Arg., *Cleistanthus myrianthus* (Hassk.) Kurz and *Syzygium lineatum* (DC.) Merr. & L.M. Perry. From the seven species *V. pinnata*, *S. scortechinii* and *S. polyanthum* performed best in both survival and growth rates. This study suggests those three species are excellent local tree species for ex-coal mining rehabilitation, not only because of their high survival rate (≥80%) and fast-growing but also they produce favourable fruits and flowers for wildlife.

Keywords: Rehabilitation, local tree species, post-coal mining area

PERTUMBUHAN BEBERAPA JENIS POHON LOKAL DI LAHAN PASCA TAMBANG BATU BARA DI KALIMANTAN TIMUR. Daerah bekas tambang batu bara perlu rehabilitasi untuk mengembalikan fungsinya. Namun, tidak semua jenis tanaman dapat tumbuh dengan baik di lahan bekas tambang batu bara, karena kawasan yang terbuka menjadikan intensitas cahaya matahari berlebihan dan fluktuasi suhu yang ekstrim. Penelitian ini bertujuan untuk menentukan jenis pohon lokal yang cocok untuk merehabilitasi areal bekas tambang. Penanaman dilakukan pada bulan November 2012, dan observasi dilakukan pada bulan November 2015. Lokasi penelitian berada di Kabupaten Samboja, Kutai Kartanegara, Provinsi Kalimantan Timur. Hasil penelitian menunjukkan bahwa terdapat tujuh jenis pohon yang mampu bertahan hidup dengan baik di lahan bekas tambang batubara, yaitu Vitex pinnata *L., Syzygium scortechinii (Merr.) Merr. & Perry,* Syzygium polyanthum *(Wight) Walp.,* Shorea balangeran *(Korth.) Burck,* Macaranga motleyana *(Mull.Arg.) Mull.Arg.,* Cleistanthus myrianthus *(Hassk.) Kurz dan* Syzygium lineatum *(DC.) Merr. & L.M.Perry. Dari tujuh spesies tersebut,* V. pinnata, S. scortechinii *dan* S. polyanthum *tercatat memiliki pertumbuhan terbaik dan mampu bertahan dalam lahan terbuka. Studi ini menunjukkan bahwa ketiga spesies tersebut adalah spesies pohon lokal yang disarankan untuk merehabilitasi tambang batu bara, tidak hanya karena tingkat hidupnya tinggi (≥80%) dan cepat tumbuh, namun juga menghasilkan buah dan bunga yang menguntungkan bagi satwa liar.*

Kata kunci: Rehabilitasi, jenis pohon lokal, area pasca tambang batu bara

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I. INTRODUCTION

In the National Energy Conservation Master Plan, it is mentioned that coal is promoted to be one of the primary energy sources in Indonesia by 2020 including East Kalimantan Province (Kusmana, Setiadi, & Al-Anshary, 2013). Coal is one of the primary energy sources to generate electricity, which is essential to support economic growth for East Kalimantan and also for the whole country. The contribution of mining and quarrying sector to the economy in this province is estimated to increase from 36.2% to 50.5% from 2001 to 2011(Ishak, 2013). However, coal mining has resulted in negative environmental impacts such as loss of biodiversity (Pandey, Agrawal, & Singh, 2014), degradation of the watershed quality and quantity (Merem et al., 2014; Zegre, Miller, Maxwell, & Lamont, 2014), as well as toxicity in the aquatic environment (Turner et al., 2013). Therefore, sustainable coal mining practices in East Kalimantan need to be promoted by reducing its negative impacts on the environment.

Reclamation and rehabilitation of post-coal mining areas need to be conducted to reduce the negative impacts of coal mining activities on the environment. These activities ensure ecosystem services to recover to the previous functions, which are essential to support human well-being and prevent further negative impacts on the ground (Yassir, 2013). Furthermore, based on the national regulation Act No 4/ 2009 about Mineral and Coal Mining in Indonesia, rehabilitation and reclamation after coal extractions are an obligation for the mining concession holders in this country. Therefore, reclamation and restoration are an essential activity to support sustainable mining in Indonesia (Mansur, 2010).

In the coal mining area rehabilitation projects, the use of local tree species in the species selection is one of the key factors to the success of the project. The local tree species have several advantages, such as more adaptive to the environment, maintaining the genetic integrity of the population of local species, preventing the invasion of exotic or non-local species (Gray, 2002). Besides, these local plant species could also contribute to the conservation programs. Unlike exotic plant species, the use of local plant species has minimum impacts in altering the species composition and structure of the landscape from the previous state before mining activities were conducted. On the other hand, the use of exotic plant species has some negative impacts on the environment and conservation programs (Radiansyah et al., 2015).

The success of revegetation can be evaluated by determining the plant's growth performance (Istomo, Setiadi, & Putri, 2013). Growth performance, which can be described as plant's height, diameter and survival rate, is an important aspect to observe in this study because it can be the indicators for plant species evaluation in adapting to a new environment. Environmental conditions in the post-coal mining area are different compared to the native habitat of the ten local plant species in this study. A study conducted by Villacís, Casanoves, Hang, Keesstra, and Armas (2016) by measuring height, tree diameter, and survival rate as growth parameter for 20 plant species in the rehabilitation of post-oil mining areas in Amazon Basin. That study aimed to provide a list of plant species suitable for post-oil mining rehabilitation. Meanwhile, a study conducted by Todd, Rufaut, Craw, and Begbie (2009) used plant survival and plant height growth in an opencast coal mining rehabilitation using indigenous plant species in New Zealand. Besides, Mushia, Ramoelo, and Ayisi (2016) used plant height, plant cover and plant biomass as growth indicators in a study determining the impacts of coal mine stockpile quality on plant growth and productivity.

In 2012, a rehabilitation project of the post-coal mining area had been conducted by planting ten local tree species in East Kalimantan, Indonesia (Adman & Yassir, 2016). The study reported that three tree species had a survival rate of more than 90% at the age of one year, indicating that they can grow well on post-coal mining areas. Those species are *Vitex pinnata* L., *Syzygium scortechinii* (King) P. Chanaranothai & J. Parnell, Kew, *Syzygium polyanthum* (Wight)

Walp. It is also reported that although they had a low survival rate, *Bridelia glauca* Blume and *Ficus variegata* Blume, could again grow well on post-coal mining land during the first year. According to a study, the critical period occurred between one to two years after planting for plant establishment in the tropical areas (Villacís et al., 2016). Therefore, this study aimed to evaluate the further performance of the ten local tree species planted in post-coal mining areas in East Kalimantan. This paper reported the growth performance of the ten local tree species in the post-coal mining area at the age of 4 years. It is crucial to provide alternative local plant species that are suitable to the local environment, which is also essential for conservation programs rather than exotic species.

II. MATERIAL AND METHOD

A. Study Site and Materials

The study area was a post-coal mining land at S01°00'44.1" E116°54'27.2", located in the district of Samboja, Kutai Kartanegara, East Kalimantan Province, Indonesia. The study was carried out in November 2012 by planting ten local tree species in one of the company's post-mining areas. The selection of the ten species (Tabel 1) was based on recommendations of the study reported by Yassir and Omon (2009).

B. Methods

Seedlings (wildlings) of the ten local plant species were collected from the forests located around the mining areas. After collection, the seedlings were transported and maintained in the nursery under 50% shading. Pot size used was 10 x 15 cm filled with a mixture of topsoil and compost with a ratio of 1: 1 (v/v). During the first three months, seedlings were kept under a lid. The lid was used to keep the humidity high (>80%). Watering inside the lid was done at humidity less than 80%. After the seedlings produced new shoots, the lid was opened gradually starting from 10% opening for the 1st week, then 25% at the following week, then 50%, 75% to 100% opening, respectively with a one-week interval. After the lid opened 100%, the seedlings were kept in the nursery until they were ready for planting (± 5-7 months). Watering in the nursery was done twice a day, if it did not rain, to maintain humidity, and it was reduced if it is raining.

The seedlings were also sorted to obtain a uniform size in diameter and height before planting. Meanwhile, the planting area was covered by topsoil with ± 50 cm thickness based

Table 1. The botanical name of local plant species planted in this study

No	Botanical name	Family	Local name	Uses
1.	*Vitex pinnata* L.	Lamiaceae	Laban	Wood construction, firewood, medicinal plant
2.	*Syzygium polyanthum* (Wight) Walp	Myrtaceae	Salam	Flavouring spices, medicinal plant
3.	*Cleistanthus myrianthus* (Hassk.) Kurz	Phyllanthaceae	Jari-jari	-
4.	*Syzygium lineatum* (Blume) Merr. & Perry	Myrtaceae	Gelam tikus	Wood construction, medicinal plant, fruits edible
5.	*Syzygium scortechinii* (Merr.) Merr. & Perry	Myrtaceae	Obah air	Fruits edible
6.	*Bridelia glauca* Blume	Phyllanthaceae	Kanidei	Wood construction, fruits edible
7.	*Ficus variegata* Blume	Moraceae	Nyawai	Wood construction, fruits edible
8.	*Schima wallichii* (DC) Korth.	Theaceae	Puspa	Plywood, pulp for paper, medicinal plant
9.	*Macaranga motleyana* (Müll. Arg.) Müll. Arg.	Euphorbiaceae	Mahang	-
10.	*Shorea balangeran* (Korth.) Burck	Dipterocarpaceae	Kahoi	Wood construction.

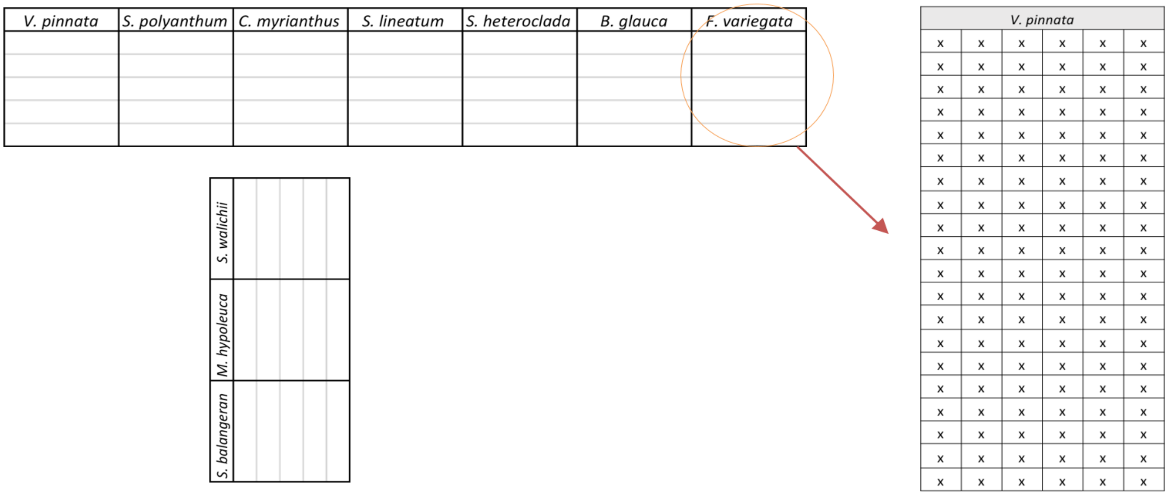

Figure 1. Planting layout and research design

on the company's standard operating procedure before planting. The size of the planting holes was 30 cm in length, width and depth. Each of the planting holes was filled with ± 1 kg compost and mixed with the soil for fertilization of the plants. The compost was made from decomposed remains of plants. The compost was applied once before planting. Each plant species was planted in six lines, consisting of 20 plants in each line, with 3 m x 3 m spacing (Figure 1). Therefore, 1200 plants were planted in the area, and the dead plants were not re-planted. This layout was implemented due to the availability of the post-coal mining area in the company. After planting, weeding was also regularly conducted four times a year to eliminate weeds and providing growing space for the plants. Planting holes, compost dosage and plant spacing, were based on standard operating procedures applied by PT. Singlurus Pratama.

Observations on the growth of the ten local plant species were regularly conducted every six months up to the age of four year. Data collection included plants' survival rates, heights and diameters at planting and after four years after planting and soil chemical characteristics before and after three years of planting. Survival rate was indicated by the percentage of plants that survived divided by the total number of planted plants. Plant's height was consistently measured from the ground level to the highest top of the plant, while the diameter was measured at ± 10 cm above ground level.

C. Analysis

ANOVA (analysis of variance) was performed to identify species performances among the ten local plant species. It was followed by Tukey HSD test if the analysis of variance showed a significant difference between variables. The ANOVA result tables will not be shown, but the results of the Tukey HSD Test will be shown in histograms, and the statistical difference will be distinguished by letters. Before the analysis of variance, the data were tested to identify the normality, and if the data were not distributed normally, then they will be transformed using logarithms. Beside ANOVA, the height and diameter growth data are also depicted by using a graphic to observe the growing patterns.

III. RESULT AND DISCUSSION

A. Plant Survival Rates of the 10 Local Tree Species in the Post-Coal Mining Land

The results showed that seven of the ten local plant species planted on the post-coal mining area had survival rates above 80% at the age of four years. Among seven species, three of them had a survival rate above 90%, i.e. *S. polyanthum*, *S. scortechinii* and *V. pinnata* (Figure 2). Survival rate indicates the number of surviving plants in the research site, including plants that grow slowly or it is in static growth. There were also three species having survival rates below 70%; i.e. *F. variegata*, *B. glauca* and *S. wallichii*, in which *F. variegata* had the lowest value, 32%.

In the first observation year, these three plant species also had low survival rates compared to the other seven local plants planted on the research site (Adman & Yassir, 2016). However, in general, plant death had occurred to almost all species of plants observed from 1 year to 4 years. It is indicated by a decrease in the plant's survival rate, except for *V. pinnata*, which showed consistently 100% survival rate. This means that death has occurred to the nine species of plants at a different rate. The decrease in the survival rate of plants indicates that some species were unable to adapt to the extreme mining environment at a different level. The reduction in survival rate from the 1 to 4 year varied between the ten local plant species. Five species have a decrease rate of less than 10%, i.e. *S. lineatum* (1.67%), *S. scortechinii* (2.50%), *S. wallichii* (3.34%), *C. myrianthus* (4.17%) and *S. polyanthum* (6.66%). The other species have a decrease rate below 20%, i.e. *S. balangeran* (13.33%), *M. motleyana* (15.00%) and *B. glauca* (16.67%). Meanwhile, *F. variegata* has the highest decrease rate of 36.50%.

Analysis of variance on the survival rate of the ten local tree species showed that the survival rate between species was significantly different. The result of multiple range tests and the details of plant survival rates are presented in Figure 2.

B. The Average Height and Diameter Growth of the Ten Local Tree Species in the Post-Coal Mining Land

From ANOVA, it can be said that there were significant differences in terms of height and diameter growth rate among the ten local plant species tested in this study, as indicated in the results of multiple range tests (Figures 3 and 4). From the figures, several groups can be categorized by the plant growth in terms of height or diameter. The first group was *V. pinnata*, which had the most significant growth both in height and diameter compared to the other nine plant species during the four years. It grew by almost 5 m in height and 7.22 cm in diameter. Meanwhile, *S. polyanthum*, *S. balangeran* and *S. scortechinii* can be categorized as the second most impressive species in terms of height growth, with about 3 m growth in the four years. The third group of growth in terms

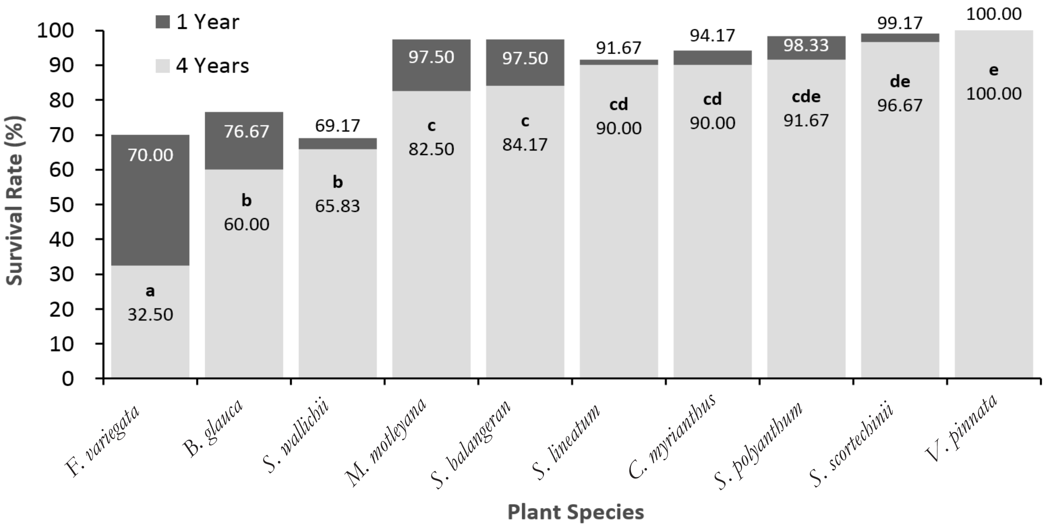

Figure 2. The survival rates of ten local tree species at years 1 and 4 in post-coal mining land, PT SGP (The same letters are not significantly different at 95% confidence level in Tukey HSD Test)

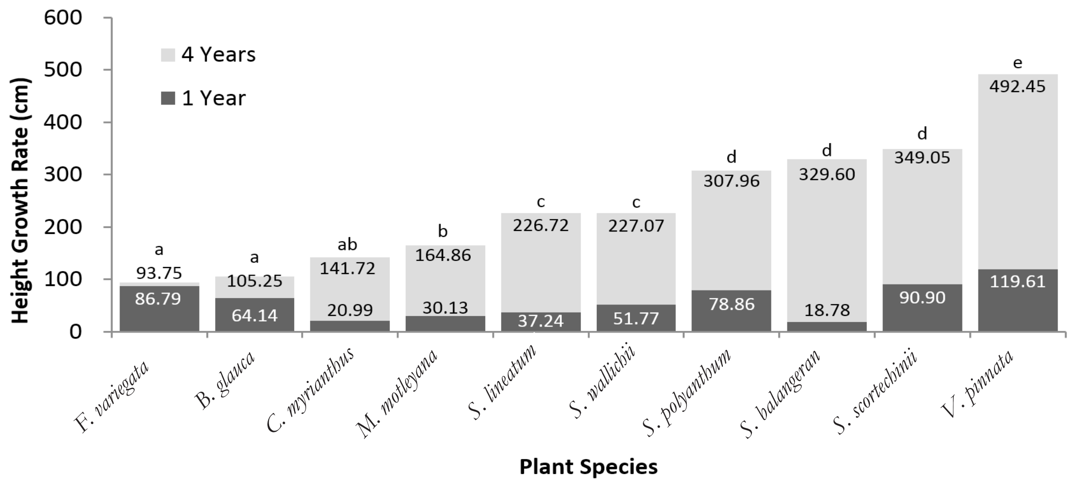

Figure 3. The height growth of ten local tree species at four years in post-coal mining land, PT SGP (The same letters are not significantly different at 95% confidence level in Tukey HSD Test)

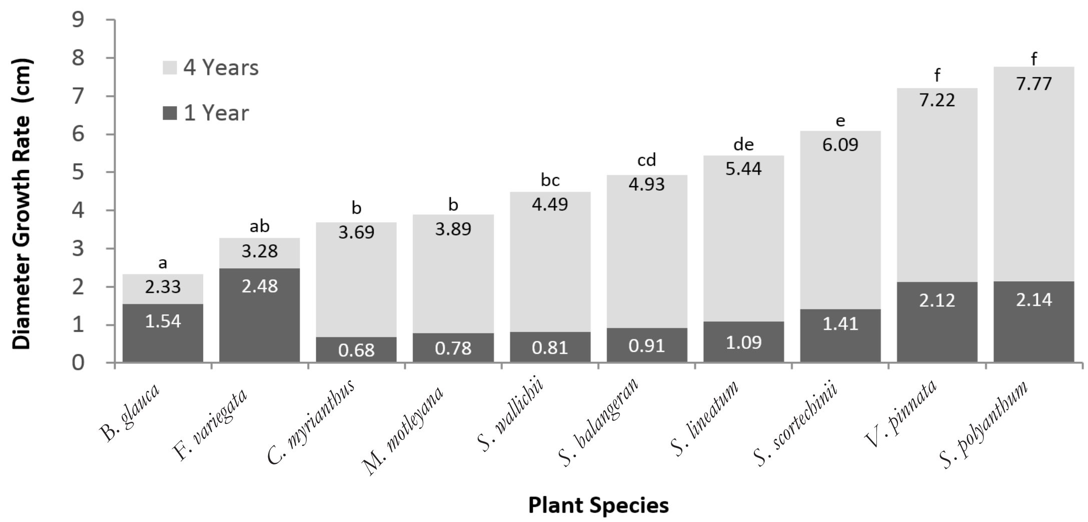

Figure 4. The diameter growth of ten local tree species at four years in post-coal mining land, PT SGP (The same letters are not significantly different at 95% confidence level in Tukey HSD Test)

of height was *S. lineatum* and *S. wallichii*, then followed by *C. myrianthus* and *M. motleyana* as the fourth group.

In terms of diameter, *S. polyanthum* can be categorized as the most impressive because its growth is close to *V. pinnata*, growing by about 7 cm during the four years. Meanwhile, *S. balangeran*, *S. lineatum* and *S. scortechinii* can be placed in the same group, with diameter growth range from 4.9 to 6 cm in the same period. The next group is *C. myrianthus*, *M. motleyana* and *S. wallichii*, with diameter growth from 3.5 to 4.5 cm during the same period. The last group is *F. variegata* and *B. glauca*, which can be considered to have the slowest growth, in terms of height and diameter compared to the other species.

C. The Growth Pattern of the Ten Local Plant Species in the Post-Coal Mining Land

The growth pattern of ten local plant species is presented in Figures 5 and 6. From the figures, in general, all species observed in this study experienced slow growth in terms of 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 of almost all plant species observed. If we study the growth pattern in more detail, the growth acceleration occurred from month 12th to 30th. In the subsequent months, particularly from months 30th to 36th, the height and diameter growth was slower than in the previous period. Finally, in the subsequent period, from months 36th to 48th, the height and diameter growth began to accelerate, except for *B. glauca*.

In Figures 5 and 6, *V. pinnata* had shown a consistent and significant growth pattern in both diameter and height compared to the other plant species. Furthermore, although the diameter growth began to de-accelerate at the 30th months, this species' height growth is started to re-accelerate again in the 36th month. Meanwhile, *S. balangeran*'s height growth shows different pattern compared to the other species, after experiencing rapid growth during the first 30 months period, the height growth stagnated instead of growing from month 30th to 36th. This is because of a significant number of *S. balangeran* were experiencing 'partial death' during that time; therefore, the heights were measured at the new part of the plants that just grew from month 30th to month 48th. Partial death means that part of the total height of the plant is dead, which is followed by the growth of several new shoots in the plants in the subsequent period. On the other hand, *B. glauca* and *F. variegata* show different height growth pattern. After a slow growth in the first two years, they experienced stagnation in height growth from 24th month to 48th month, which was also caused by partial death in some plants.

In Figure 6, *S. polyanthum*, *V. pinnata*, and *S. scortechinii* have similar diameter growth pattern, showing the most significant and consistent growth up to the first 30th month and slightly decreasing in the subsequent 18 months, compared to the other species. Meanwhile, *B. glauca* and *F. variegata* show relatively similar diameter growth pattern with their height growth pattern. The slow diameter growth of the two species has occurred up to month 30th. While *F. variegata* experienced a slight increase in the diameter growth from month 30th to 36th followed by a continued stagnation (*the tree cannot grow negatively*) up to month 48th, *B. glauca* had experienced a steady decrease in diameter growth since month 30th.

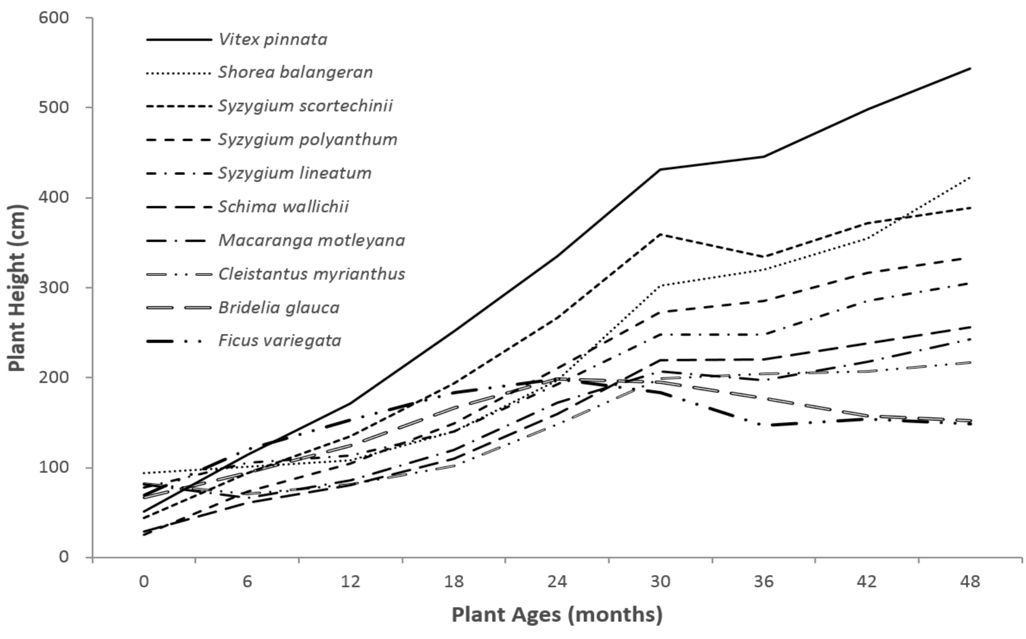

Figure 5. Height growth trends of ten local tree species after four years planted in post-coal mining land, PT SGP

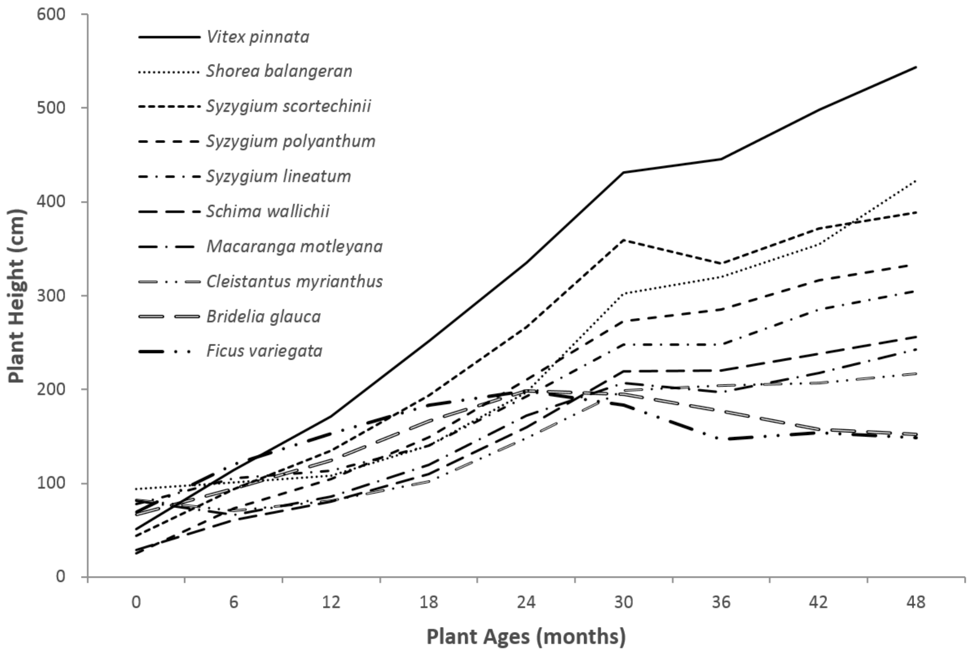

Figure 6. Diameter growth trends of ten local tree species after four years planted in post-coal mining land, PT SGP

D. Plant Adaptation to the Environment of Rehabilitation Area

The main cause of the slow growth of almost all species of plants in the first year was due to the adaptation process from the nursery to the rehabilitation area. There were dramatic environmental changes from the nursery, in which the plants were kept before planted into the mining area, which is characterized by an open area, water-shortage, extremely high temperature, and soil compaction. On the other hand, in the nursery, the plants were controlled in a relatively cool temperature and well maintained. Furthermore, there is four typologies of soil degradation; highly degraded lands, moderately degraded lands, slightly degraded lands and improving lands (FAO, 2011). The severity of soil degradation in the post-mining areas can be categorized as highly degraded; in this type of degradation, the intervention option needed is rehabilitation. As a result, some plant species might need considerable time to adapt to the rehabilitation area.

Stressful environmental condition like water shortage in the post-coal mining areas during the first year of rehabilitation might result in a decrease in the amount of chlorophyll in the leaves of the plants (Ramírez et al., 2014). Death can occur to the plants; simply, they did not survive. However, the survived plants would re-sprout and re-grow. Nevertheless, some of the local tree species planted could re-sprout, but each of the plant species had different times to re-sprout and re-grow. Therefore, the ability to re-sprout is important for plants to survive and grow in post-coal mining land as a form of adaptation to extreme environmental conditions.

The other abiotic stress in the post-coal mining rehabilitation areas is the high temperature. A review reported that heat stress has some negative impacts on plants, depending on species types, genotype and heat duration (Bita & Gerats, 2013). From the review, there are several visible impacts to the plants resulting from high temperature; burned or senescence leaves and stems, damage of fruit and suppressing root growth leading to plant productivity loss. The review also reveals that heat stress can change the respiration and photosynthesis of the plants, causing a decrease in plant productivity and shortened life cycle. It is also shown that a 5ºC increase in temperature above the normal condition can lead to a reduction in protein synthesis in the cellular system. Besides, heat stress also has some adverse impact on the molecular level of plants affecting the photosynthesis (Allakhverdiev et al., 2008). In the ecosystem, heat stress can cause tree mortality in the forest ecosystem (Anderegg, Kane, & Anderegg, 2013). Therefore, the slow growth of the ten local species in the first year after planting was caused by high temperature.

Although the analysis of the physical properties of the soil was not done, the issue of soil compaction is also one of the main features that potentially inhibiting plant growth. A review reported that severe soil compaction could result in stunted growth of shoot, root deformation and high mortality rate (Nawaz, Bourrié, & Trolard, 2013). From the review, it was also revealed that soil compaction also reduced the soil biodiversity; reducing the number of soil fauna and flora, enzymatic activity and microbial biomass. Moreover, a study reported that there were significant differences in terms of soil microbial communities between soil from post-mining areas and undisturbed soil, in which the controlled soil areas had higher microbial diversity compared to the soil of post-mining regions (de Quadros et al., 2016). However, another research showed that there was no difference in terms of growth and survival rates between trees planted in compacted soil and un-compacted soil in the post-mining areas in West Virginia, the USA (Emerson, Skousen, & Ziemkiewicz, 2009). This might be due to the age of seedlings planted in the study, which was two years old. Meanwhile, in this study, the age of the seedlings when they were planted was unknown because the seedlings were obtained from the natural forests. Thus, the compacted soil in this study might have a negative impact on plant growth, resulting in slow diameter and height development in the first year.

The analysis of soil chemical properties (Table 2) shows that among species, the pH values were generally very acid and decreased from 3.83–4.57 to 3.38–4.06. The Cation Exchange Capacities (CEC) varies, some have increased, and some dropped, although all are still in the low category. The N total increased under several species from very low to the standard type; otherwise, the C/N ratio generally decreased. The concentration of P_2O_5 and K_2O were growing, especially for K_2O that significantly increased, from low-medium to high-very high.

E. Plant Growth

During four years, *V. pinnata* had a remarkable growth performance, indicated by reasonable survival rate, diameter and height growth, compared to the other nine species. This species also had relatively better adaptation to the environment in the early

Table 2. Local plant species planted in this study

No	Species	pH		CEC (meq./100 gr)		N Total (%)		C/N ratio		P2O5 (ppm)		K2O (ppm)	
		0 Year	3 Years	0 Year	3 Years	0 Year	3 Years	0 Year	3 Years	0 Year	3 Years	0 Year	3 Years
1.	*Vitex pinnata*	3.83$^{1)}$	3.38$^{1)}$	5.62$^{b)}$	9.79$^{b)}$	0.04$^{a)}$	0.11$^{b)}$	20.0$^{d)}$	8.07$^{b)}$	0.86$^{a)}$	5.71$^{a)}$	14.39$^{b)}$	71.24$^{e)}$
2.	*Syzygium polyanthum*	4.34$^{1)}$	3.60$^{1)}$	7.84$^{b)}$	7.87$^{b)}$	0.06$^{a)}$	0.10$^{b)}$	14.9$^{c)}$	8.76$^{b)}$	0.94$^{a)}$	1.30$^{a)}$	19.63$^{b)}$	49.59$^{d)}$
3.	*Cleistanthus myrianthus*	4.08$^{1)}$	4.06$^{1)}$	7.35$^{b)}$	7.70$^{b)}$	0.03$^{a)}$	0.10$^{b)}$	33.1$^{e)}$	8.30$^{b)}$	0.43$^{a)}$	5.71$^{a)}$	14.59$^{b)}$	57.99$^{d)}$
4.	*Syzygium lineatum*	4.38$^{1)}$	3.82$^{1)}$	6.16$^{b)}$	7.41$^{b)}$	0.06$^{a)}$	0.11$^{b)}$	14.0$^{c)}$	12.04$^{c)}$	0.77$^{a)}$	2.47$^{a)}$	8.18$^{a)}$	57.67$^{d)}$
5.	*Syzygium scortechinii*	4.54$^{1)}$	3.68$^{1)}$	7.45$^{b)}$	8.83$^{b)}$	0.06$^{a)}$	0.08$^{a)}$	14.2$^{c)}$	11.58$^{c)}$	0.94$^{a)}$	2.47$^{a)}$	11.01$^{b)}$	47.98$^{d)}$
6.	*Bridelia glauca*	4.57$^{2)}$	3.92$^{1)}$	7.06$^{b)}$	6.70$^{b)}$	0.06$^{a)}$	0.05$^{a)}$	15.3$^{c)}$	15.68$^{c)}$	1.29$^{a)}$	1.30$^{a)}$	12.66$^{b)}$	37.96$^{c)}$
7.	*Ficus variegata*	3.87$^{1)}$	3.86$^{1)}$	7.08$^{b)}$	6.93$^{b)}$	0.05$^{a)}$	0.10$^{b)}$	17.5$^{d)}$	7.84$^{b)}$	0.86$^{a)}$	0.65$^{a)}$	13.01$^{b)}$	23.74$^{c)}$
8.	*Schima wallichii*	4.42$^{1)}$	3.85$^{1)}$	5.49$^{b)}$	7.88$^{b)}$	0.06$^{a)}$	0.09$^{a)}$	14.9$^{c)}$	9.89$^{b)}$	1.29$^{a)}$	2.47$^{a)}$	20.52$^{b)}$	54.44$^{d)}$
9.	*Macaranga motleyana*	4.55$^{2)}$	3.73$^{1)}$	7.31$^{b)}$	7.29$^{b)}$	0.06$^{a)}$	0.07$^{a)}$	13.7$^{c)}$	14.04$^{c)}$	2.15$^{a)}$	4.41$^{a)}$	17.49$^{b)}$	47.33$^{d)}$
10.	*Shorea balangeran*	4.52$^{2)}$	3.69$^{1)}$	4.84$^{b)}$	6.32$^{b)}$	0.07$^{a)}$	0.07$^{a)}$	9.5$^{b)}$	10.12$^{b)}$	0.86$^{a)}$	2.47$^{a)}$	32.38$^{c)}$	41.19$^{d)}$

Remarks: $^{1)}$ Very acid; $^{2)}$ Acid; $^{a)}$ Very Low; $^{b)}$ Low; $^{c)}$ Medium; $^{d)}$ High; $^{e)}$ Very High (Based on Hardjowigeno, 1995) stage of the rehabilitation process, which can be shown in the consistent trend of diameter and height growth (Figure 5 and 6) during the four years. *V. pinnata* was one of the dominant plant species in the regeneration process of the tropical rainforest after fire disturbances, which therefore was categorized as a pioneer species (Yassir, van der Kamp, & Buurman, 2010).

From their study, it can be indicated that *V. pinnata* requires a significant amount of sunlight to grow, which is abundantly available at the post-coal mining land at the beginning of the planting process. There was the limited study about the growth of *V. pinnata*, but a study showed that this species is one of the most adaptive plant species growing in the post-tin mining areas in Bangka, Indonesia (Nurtjahya, Franklin, Umroh, & Agustina, 2017). However, if compared to other fast-growing pioneer species such as *Paraserianthes falcataria*, *V. pinnata* has significantly lower height and diameter growth. *P. falcataria*, which is an exotic species, can reach 3.4–16.7 cm of diameter and 3.9–19.6 m of height at the age of about four years in West Java, Indonesia (Krisnawati, Varis, Kallio, & Kanninen, 2011). Nevertheless, the use of fast-growing exotic species in the rehabilitation of post-coal mining area is allowed based on regulations in Indonesia. However, it might have some consequences for biodiversity conservation (Nugroho & Yassir, 2017).

In this study, *F. variegata* and *B. glauca* had poor growth performance, which can be indicated by low survival rates and slowest diameter and height growth among the other species. *F. variegata*, has been used in some tropical forest restoration projects because of its role as a keystone species (Kuaraksa & Elliott, 2013) and pioneer (Kuaraksa, Elliott, & Hossaert-Mckey, 2012). Still, this species seemed unable to adapt in the post-coal mining environment. For example, at the age of 2 years, the growth of *F. variegata* was 6–8 cm diameter, and 6.9 m height in Java applied in the intercropping system (Effendi, 2012). In another study, this species can reach 6.2 cm diameters and 5.1 m height in East Kalimantan in a monoculture planting system (Effendi & Mindawati, 2015). However, the levels of soil degradation in the intercropping and monoculture systems were different than the soil degradation in the post-coal mining areas. The soil in the post-mining area has experienced the heaviest soil degradation compared to the other methods because of heavy machinery activities during surface removal. As a result, the environmental stress in the post-coal mining areas is more intense than ecological stress in the intercropping and monoculture systems, resulting in the slow growth of *F. variegata*.

The inability to adapt in the post-mining areas might also be the case for the poor growth performance of *B. glauca*. Other study showed that *B. glauca*, along with *V. pinnata*, was one of the dominant plant species identified in a secondary forest after ten years regeneration from imperata grassland because of fire disturbances, indicating that *B. glauca* is a pioneer species, demanding direct sunlight for supporting its growth which is abundantly available in the post-mining areas (Komara, Murtinah, & Arbain, 2018; Yassir, 2016). Meanwhile, this species was found in a succession area of degraded forest (Gunawan, 2015). However, *B. glauca* might not be able to grow naturally in the heavily degraded soil such as in the post-coal mining areas. Nevertheless, the information about the growth of *B. glauca* is limited; therefore, it is difficult to compare its growth. A study reported that *B. glauca* could grow to a height of up to 10 m, initially distributed in Okinawa, Japan, Taiwan, Southern part of China, Indochina and the Philippines (Ngueyem, Brusotti, Caccialanza, & Finzi, 2009).

Meanwhile *S. polyanthum* had the most massive diameter growth but moderate height growth compared to the other nine plant species. However, *S. polyanthum* growth in this study was remarkable compared to other studies. A study reported the diameter growth of *S. polyanthum* planted in the restoration of degraded forest in Singapore can reach about 1 cm per year with the average diameter of about 3.5 cm at the age of 4 years (Shono, Davies, & Chua, 2007). The other study showed that at the period of 14 months, *S. polyanthum* had 29.06 cm of height and 0.7 cm of diameter, which was planted in a nature tourism park degraded area with the intercropping system (Sumarhani, 2015). Thus, by considering the level of degradation, which is heavier in the post-coal mining areas than the level of degradation in the other studies, *S. polyanthum* might be able to adapt to the post-mining regions in this study. This species is also known as a medicinal plant (Har & Intan, 2012; Widyawati et al., 2015).

The other species in this study, *Sh. balangeran*, *S. lineatum* and *S. scortechinii* showed consistent moderate diameter and height growth compared to the other species. *S. balangeran* showed a significant increase in diameter and height growth which occurred since the month 42nd, after a slow growth during the first 12 months. This indicates that this species might grow well in the post-mining environment. However, the development of *S. balangeran* in the first year in this study is slower compared to several studies. A similar study reported that *S. balangeran* could grow by 19 cm in height and 0.5 mm in diameter during the first year, grown under the shaded area of 4 years old fast-growing plants, Samanea saman (Susilo, 2016), and another study show it grows by 146–149 cm of height and 1.5–3.0 cm of diameter at five years old in post-coal mining land (Lestari, Fiqa, Fauziah, & Budiharta, 2019). This indicates that shaded areas are essential for *S. balangeran* during the first years after planting in the post-mining environment.

On the contrary, another study reported that *S. balangeran* could grow well in the un-shaded imperata grassland, growing by 64–71 cm of height and 8–10 mm in diameter at the first year at various land preparations (Yassir & Mitikauji, 2007). It is important to note that the level of degradation in the imperata grassland was much lower than the level of degradation in the post mining areas, causing significant growth of *S. balangeran* in the first year. In addition, this species is also reported as one of the plants for peat swamp restoration project (Graham, Turjaman, & Page, 2013). Furthermore, *S. balangeran* was said to have about 2.7 cm of stem diameter at the age of 40 months, planted in the peat swamp forest in Central Kalimantan (Turjaman et al., 2011), slightly lower than the diameter growth in this research. This indicates that *S. balangeran* can grow in various environments.

Compared to the other studies, the diameter and height growth of *S. lineatum* in this study was acceptable. A study reported that this species could grow by 0.28 cm in height and 0.76 cm in diameter in the first year (Rahman et al., 2011). Meanwhile, in this study, the height and diameter growth of *S. lineatum* was stagnated during the first year but started to grow consistently from the 2nd to 4th year. This indicates that this species can adapt and grow in a heavily degraded environment such as in the post-mining areas.

Furthermore, *S. lineatum* can also grow in the succession areas in an abandoned grazing site in West Java, Indonesia (Rosleine & Suzuki, 2012). This indicates that this species is pioneer species-meanwhile, works of literature about *Sy. Scortechinii* is limited; therefore, it is hard to compare its growth in another environment.

The other species; *S. wallichii*, *M. motleyana* and *C. myrianthus* had low to the average but the consistent diameter and height growth in the four years compared to the other species. However, it is difficult to evaluate the growth performance of these three species due to limited works of literature. Based on available pieces of literature, *S. wallichii*, *M. motleyana* and *C. myrianthus* can be categorized as pioneer species, appearing after disturbances in a forest ecosystem. For example, *S. wallichii* was reported appearing in an abandoned coal mining site in India, in which the coal extraction was conducted using 'rat-hole' mining method (Sarma, Kushwaha, & Singh, 2010). The other study showed that *S. wallichii* grows in a natural succession area after the volcanic eruption, although this species was not a dominant plant (Suryanto, Zaki, Azani, & Azmy, 2010).

Meanwhile, another study shows that *C. myrianthus* was a plant species in the secondary forests (Yusuf & Purwaningsih, 2012). Also, *M. motleyana* was a pioneer species that reported to dominantly inhabit the low to intermediate disturbance (Slik, Keßler, & van Welzen, 2015) level forest. Nevertheless, in the high level of disturbances such as mining activities in this study, in which the soil experience compaction, these tree species might still be able to grow, but they need time to adapt to the post-mining environment during the first year.

Increasing plant growth needs input technology. Soil management that preserves soil nutrients and prevents acidification is likely key to the success of reforesting post-mining land (Woodbury et al., 2020). The use of mycorrhizae can be a solution to improve soil quality and plant growth. Application of mycorrhizae could improve some chemical soil properties such as pH, soil organic C, total soil N, and available P (Agus, Primananda, Faridah, Wulandari, & Lestari, 2019; Wulandari, Saridi, Cheng, & Tawaraya, 2016).

IV. CONCLUSION

In conclusion, almost all plant species in this study have been able to grow and to adapt to the post-coal mining land, and only 2 out of 10 species were unable to adapt in this environment. In this study, *V. pinnata* had the most significant growth performance compared to the other nine species. *S. polyanthum*, *S. scortechinii* and *S. lineatum* also had a good growth performance in the post-coal mining land. Even though as a climax forest species, *S. balangeran* had an excellent performance in an open area such as post-coal mining land.

In the early period after plantation, all species experienced slow growth due to adaptation to the post-mining environmental condition, after 12 months the development of the ten species increased at a variable rate. Only two species; *B. glauca* and *F. variegata* experienced a decrease in diameter and height growth two years after planted.

V. pinnata, *S. polyanthum*, *S. scortechinii*, *S. lineatum,* and *S. balangeran* can be recommended as revegetation plants for the rehabilitation of post-coal mining land. Trials should be undertaken on other local trees and local climax trees to support the success of the rehabilitation of post-coal mining land mainly located in the forest area.

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