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REFORESTATION IN THE RECLAMATION AREA OF PONGKOR GOLD MINING

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ABSTRACT

Ex-mining land is categorized as land with a high level of degradation. The loss of biodiversity, low soil fertility, loss of several layers of soil horizons, unbalanced texture, and even contamination can occur due to mining activities. Reforestation of mining land has been carried out with the approaches of improving the physical properties of the soil, selecting plant types, and improving soil biology in ex-gold mining land in Bogor. The addition of compost significantly increased organic matter content, C/N ratio, macronutrients (N, P, K) content, and improved soil texture. The application of Mycorrhiza and Rhizobium significantly increased the growth of forest plants such as trembesi (Samanea saman), gmelina (Anthocepalus cadamba), and ganitri (Elaeocarpus angustifolus) in ex-gold mining areas. Applying that significantly improved vegetation diversity on ex-gold mining land, including more than eight types of understory plants, and more than five plants were from the trees group. The result showed that reforestation of ex-mining land was feasible if it was carried out with a comprehensive approach.

INTRODUCTION

Mining activities, apart from contributing to the economy, also have a serious impact on land quality. Stripping of land to the lower horizon disturbs the physical, chemical, and biological properties of the soil, which causes the loss of vegetation and the decrease of biodiversity. Tailings are one of the mining wastes from the amalgamation process of earth and ore (Australian Government, 2016). A considerable amount of tailings has the potential to form land with critical characteristics such as lower organic content, more insufficient water holding due to sandy texture domination, and little macronutrient content. At the same time, it contains high micronutrient content and potentially toxic heavy metals (Setyaningsih et al., 2018). Such conditions not only become a big obstacle for land revegetation activities but also endanger the life around them. Revegetation or reforestation on land with those extreme characteristics certainly requires a comprehensive approach by carrying out appropriate land management, selecting plant species, introducing microorganisms, and providing organic materials (Setyaningsih et al., 2020; Pratiwi et al., 2021).

Mining land reclamation activities generally consist of land planning and revegetation activities (Feng et al., 2019). Because post-mining land tends to be extreme, the types of plants recommended for revegetation are fast-growing, resistant to drought or waterlogging, and resistant to marginal conditions (Chechina & Hamann, 2015). Several other considerations in selecting plant types for post-mining land include: being able to adapt, including pioneer types, growing fast, and being resistant to full sunlight, being catalytic, or those that stimulate the development of other organisms, and immediately covering the land with easy rot litter, and following land use (Setiadi & Setiawan, 2011; Chechina & Hamann, 2015). A combination of local and exotic trees, fast-growing and slow-growing trees, cover crop groups, and dendro groups is also considered to increase the success of reforestation (Pratiwi et al., 2021). Some local trees species known to grow around the Pongkor gold mining area were Waru (*Hibiscus decaspermus* Koord. & Valeton), rasamala (*Altingia excelsa*), trembesi (*Samanea* *saman*), gmelina (*Anthocepalus cadamba*) and ganitri (*Elaeocarpus angustifolus*) (PT ANTAM UBPE Pongkor, 2018). This species could be an alternative for revegetation plants.

Compost resulting from decomposition of organic matter (plants and manure) is known to increase the organic content of the land, so it has very potential to be applied to ex-mining land (Wasis & Fathia, 2011)). Arbuscular Mycorrhizal Fungi (AMF) and Rhizobium bacteria (Rhi) are known as symbiotic microorganisms with plants which can increase the absorption of macro-nutrients such as P and N and have other beneficial effects, including water absorption ((Wu et al., 2015; Chen et al., 2018), so that their utilization in revegetation is expected to provide a good contribution.

Reforestation efforts have been carried out in the Pongkor gold mining reclamation area with a comprehensive approach, such as selection of adaptive species, use of compost, application of symbiotic microbes, and intensive care. This research was aimed at determining the success of these reforestation activities by observing the physical and chemical shifts of tailings land, the growth of trembesi plants in the seedling-sapling phase and their potential in remediating Pb metal, and the structural composition of revegetation plants in the Pongkor gold mining reclamation area.

MATERIAL AND METHODS

Location

The revegetation area observed was in the concession area of PT ANTAM Tbk. Pongkor Gold Mining Business Unit is in Bantar Karet Village, Nanggung District, Bogor Regency, West Java Province. Geographically, it is located at coordinates: 106° 30' 1.0" - 106° 35' 38.0" E and 6° 36' 37.2" - 6° 43' 11.0" S with an altitude of 400 - 1800 m above sea level (MASL).

Preparation of revegetation land and planting

Each plot of the revegetated area was arranged by leveling the surface of the land, mixing it with topsoil, making drainage channels according to the flow of water, and making planting holes of 50x50x50 cm, with a spacing of 3 x 4 m. Each planting hole was put in 6 kg of compost. Seedlings of various local plants with a height average of 50-75 cm were planted in the provided holes.

Preparation of microbial inoculants and inoculation

Arbuscular Mycorrhiza Fungi (AMF) was developed by bioassay (Brundrett et al., 1996) using sorghum as host plant and zeolite as carriers and inoculated the seedling phase in polybag and when planting in the field. Rhizobium inoculant (Rhi) was prepared using rice-husk charcoal as a carrier (Oktaviani & Susanto, 2017) and inoculated 100 grams per 2 kg seed during the germination phase. AMF and Rhi inoculants were applied at the nursery and the planting time in the field (Setyaningsih et al., 2020).

Preparation of planting and microbial inoculation

Seedlings of various local plants with a height average of 50-75 cm were planted in the provided holes. Arbuscular Mycorrhiza Fungi (AMF) and Rhizobium (Rhi) inoculants were applied at the nursery and at the planting time in the field ((Setyaningsih et al., 2020).

Observation of plant growth and revegetation stand diversity

Observations on the growth of 12- and 14-month-old *S. saman* seedlings were carried out by measuring the increase in total height, stem diameter, root length, and dry biomass. Observation of the composition and structure of the revegetation stand in the reclamation area was carried out by identifying plant species, counting the number, and measuring the total height and diameter of plants in the seedling, sapling, pole, and tree phases for revegetation plant age groups 1-3, 5-7, and above ten years.

Observation plots were made in stripes, following contour lines. Sample plots were placed systematically, and the plot size was adjusted to the growth rate, with sampling intensity varying from 5-10% depending on the size of the reclamation area per age group. The size of the adult tree plot is 20x20 m, the pole is 10x10 m, the sapling is 5x5 m, and the seedling is 2x2 m. Vegetation analysis was carried out by calculating the Index of Important Value (INP) (Kuchler et al., 1976).

Visual observation of plant crowns in the reclamation area

Visualization of forest stand structure, canopy cover, and vegetation profile diagrams using the Spatially Explicit Individual-based Forest Simulator (Sexl-FS) software (Harja & Vincent, 2008), using plant type data, tree coordinates in the observation plot, tree height, free height branches, diameter, and tree crown diameter.

Observation of soil characteristics and land Pb metal content

Samples of tailings and soil taken as a mixture were analysed to determine texture, organic carbon content, macronutrients N, P, K, Mg, soil acidity, and Pb metal content that was analyzed using the American Public Health Association method (American Public Health Association, 1998) by Atomic Absorption Spectroscopy (AAS) which previously had been calibrated with a standard solution of Pb.

Data analysis

Index of Important Value (INP) (Kuchler et al., 1976)

Phase of Seedling and Sapling

INP = RD + RF……………………………...… (1)

The phase of Pole and Trees

INP = RD + RF + RDm………………………..… (2)

Note:

INP: Index of Important Value; RD: Relative Density; RF: Relative Frequency; RDm: Relative Dominance

$$Density = \frac{Number\ of\ plants\ of\ species}{of\ plot} \quad \text{……………...… (3)}$$

$$Relative\ Density = \frac{D\ of species}{D\ Total}\ x\ 100\% \quad \text{…………… (4)}$$

$$Frequency = \frac{Number\ of\ plots\ where\ found\ the\ species}{total\ Number\ of\ plot} \quad \text{.(5)}$$

$$Relative\ Frequency = \frac{F\ of species}{F\ Total}\ x\ 100\% \quad \text{………... (6)}$$

$$Dominant = \frac{Basal\ area\ of\ species}{-area\ of\ plot} \quad \text{………………….(7)}$$

$$Relative\ Dominant = \frac{Dm\ of species}{Dm\ Total}\ \text{x 100\%} \quad \text{……….(8)}$$

Seedling growth (Setyaningsih et al., 2018):

ΔGrowth =

Existing growing size – Initial growing size **…….** (9)

RESULTS AND DISCUSSION

Characteristics of post-mining land

Two main characteristics of land ex-gold mining activities in Pongkor have been revegetated, i.e., (1) land with stripped mineral soil and (2) land with tailings. The physical and chemical properties of mineral soil and tailings on the ex-gold mining reclamation land are shown in Table 1. The type of stripped mineral soil was red-yellow podzolic with a balanced texture (the proportion of sand-dust-clay content in the range of 30%), with a pH value of 3.5-5.8 or tended to be acid, the organic matter content of 2.82%, and the available macronutrient content (N, P, K) varied from low to moderate. On the other hand, in the tailings land, the texture was dominated by sand (65%) with shallow clay content, shallow organic C content (0.24%), deficient macro-nutrients availability (P=7.78 ppm, N=0.04%), while heavy metal content (Pb) tended to be high (reaching 17.3 ppm).

Table 1. Physical and Chemical Properties of Reclamation Land of Pongkor Gold-mining, West Java, Indonesia

Properties	Soil		Tailing		Mix (Tailing+Compost)	
pH (in H_2O)	5.06	TA	8	TAk	7.3	N
C %	2.82	L	0.24	VL	1.1	R
N %	0.22	L	0.02	VL	0.1	R
C/N	12.69	A	12	A	12	A
KTK cmol/kg	39.47	A	3.85	VL	19.6	A
P_2O_5 Tersedia ppm	9.90	L	6	R	255	VH
K_2O Tersedia ppm	106.72	VH	73	VH	107	VH
Ca cmol/kg	0.04	VL	22.23	VH	16.92	VH
Mg cmol/kg	0.03	VL	0.73	L	1.75	A
Pb Total ppm			114	CT*	90	
Pb available ppm			17.3	H**	6.2	H**
Sand (%)			65		46	
Dust (%)			30		41	
Clay (%)			5		13	

Note:

TAk = tend to be alkaline; TA = tend to be acid; VL = very low; VH = very high; L = Low; A = Average, N = neutral (Balai Penelitian tanah 2009); * = according Alloway (1995), ** = According PP 85 tahun 1999, CT = critical threshold, H = High

Plant growth and vegetation stand diversity

Observation of the effect of AMF+Rhi application on plant growth was only carried out on 12 and 24-month-old *S. saman* in the tailings area. Application of AMF and Rhizobium has increased the survival, growth height, diameter, biomass, and root length of *S. saman*, reaching 87%, 190.3 cm, 35.5 mm, 167.8 g, and 77.9 cm, respectively (Table 2).

Biodiversity observation on reclamation land of gold mining, Pongkor of 201.74 Ha have identified 41 families, 108 species, and 2,820 individuals of woody plants as well as 52 families, 102 species, and 28,224 individuals of cover crop, lianas, herbs, and epiphytes. Some are included in the IUCN Red List vulnerable category, such as *Dalbergia latifolia*, *Khaya anhtotecha*, *Swietenia macrophilla*. On tailings land, other local plant species have also been planted, such as gmelina (*Anthocepalus cadamba*), ganitri (*Elaeocarpus angustifolus*), mahogany (*Swietenia macrophylla*). Various groups of shrubs and grasses have appeared in the last six months of planting. In the second year of observation, at least 13 species of shurb and five species of grass were identified, including *Acmella paniculata*, *Ageratum conyzoides*, *Mimosa pigra*, *Mimosa pudica*, *Imperata cylindrical*, *Polygala paniculata.* In the revegetation area aged 1-3 years, the plants that reached the sapling level were found, while the level trees were only found in revegetation above ten years. *Elaeocarpus angustifolius* and *Acacia auriculiformis* are the most critical species in trees and pole level with IVI 300 (Table 3). On tailings land, other local plant species have also been planted, such as gmelina (*Anthocepalus cadamba*), ganitri (*Elaeocarpus angustifolus*), mahogany (*Swietenia macrophylla*). Various groups of shrubs and grasses have appeared in the last six months of planting. In the second year of observation, at least 13 species of shrub and five types of grass were identified, including *A. paniculata*, *Ageratum conyzoides*, *M. pigra*, *M. pudica*, *I. cylindrical*, *P. paniculata.* The vegetation canopy stratification was dominated by stratum C (12-20m) and D (1-4m), with canopy density reaching 77.06%. The horizontal and vertical canopy stratification performance is shown in Figure 1.

Improvement of land properties and plant growth

Application of compost had improved the physical and chemical properties of the reclamation land, such as an increase in the balance of organic C content, an increase in the solubility of macronutrients (P, N), and a decrease in the solubility of Pb in the growing media. The application of compost increased the C-organic content of the tailings up to 1.1%, decreased the pH tended to be normal, increased the clay content (13%), and increased the macronutrient content (N, P). In contrast, it decreased the solubility of Pb (6.2 ppm). Improving the soil/tailings' physical and chemical properties also encourages plant growth. The same condition was also reported that compost from oil palm bunches applied to the former coal mining area of PT Bukit Asam (PT BA) in Tanjung Enim, South Sumatra, Indonesia, increased survival and growth of samama (*Neolamarckia macrophylla* Roxb.) ((Juniarto et al., 2018).

The application of AMF and Rhizobium have improved the growth performance of forest plant seedlings. The positive role of these microbes has also been reported in several applications in ex-nickel mining areas and associated with *Canavalia ensiformis* (Akib et al., 2019), in ex-coal mining areas with *Pometia pinata* plants (Agus et al., 2019), tin mining in Bangka with *Reutealis trispermum* (Agus et al., 2017), as well as with *Leucaena leucocephala* in limestone post-mining media. AMF and Rhi helped the increase of plant growth either directly by increasing the availability of macronutrients, expanding the ability of plants to absorb macro elements, P, N, K, or through indirect mechanisms such as bio-control, or rising water uptake, etc. (Chen et al., 2018). The benefits of microbial mutualism symbiosis can also be more sustainable as long as there is colonization between these microbes and plant roots. Therefore, one application of these microbes is sufficient, especially at the seedling level, and of course, this will be efficient in nutrient input.

Since the tailings land is dominated by sand and dust, it is necessary to consider the use of a compost block model in the hope that it will help to prevent leaching to the sand during heavy rains, considering that Bogor rainfall reaches 300 – 550 mm in wet months, with 17 rainy days a month (Badan Pusat Statistik, 2021). Waterlogging on tailings land has reduced the success of the trembesi plant. Waterlog is a common phenomenon on the ground with sludge tailings texture composition dominated by sand and dust. Therefore, arranging good drainage on the reclaimed tailings land is essential.

Table 2. The growth of *S. saman* age 12 and 24 months after planting with AMF+Rhi application on the tailing area of ex-gold mining Pongkor

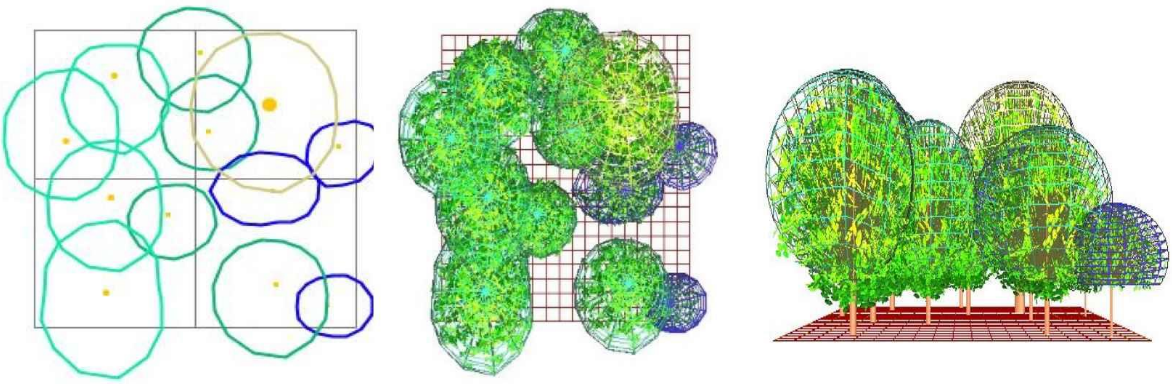
Growth variable	Control		AMF+Rhi	
	12M*	24M**	12M*	24M**
Survival (% life)	91.3	81	97.6	87
High (m)	0.23	1.46	0.35	1.91
Diameter (mm)	6.03	31.4	8.13	35.5
Biomass (g)	52.3	135.3	55.8	167.8
Root length (m)	0.31	0.46	0.42	0.78

Note: *The data have been reported (Setyaningsih et al., 2020); **Existing Observation result

Table 3. Important Value Index (IVI) of stage growth of woody plant on reclamation area of Pongkor Gold-mining, West Java, Indonesia

Revegetation age (year)	*Trees**		*Pole*		*Sapling*		*Seedling*	
	Species	IVI (%)	Species	IVI (%)	Species	IVI (%)	Species	IVI (%)
Ten up	Afrika**	95,24	Afrika	106,34	Afrika	44,05	Afrika	40,00
	Ganitri	300,00	Jati Putih	116,22	Ganitri	64,39	Matoa	100,00
	Waru Lot	76,41	Kaliandra	174,40	Kaliandra	103,73	Beunying	80,00
	Jati Putih	112,53	Kaliandra	91,24	Kaliandra	155,06	Kaliandra	134,71
	Rasamala	35,84	Rasamala	68,35	Kaliandra	42,32	Afrika	71,94
	Sonobrit	176,19	Sonobrit	300,00	Ganitri	138,10	Ganitri	100,00
	Pinus	68,80	Akasia	91,73	Puspa	36,67	Ki Harendong	66,67
	Akasia	300,00	Jati Putih	124,36	Rasamala	58,46	Ganitri	80,00
	Akasia	151,24	Puspa	122,29	Calik Angin	200,00	Ki Pare	200,00
5-7	none	0	Afrika	134,19	Afrika	53,33	Puspa	84,44
	none	0	Sengon	119,39	Ganitri	121,05	Durian	66,67
	none	0	Manglid	59,51	Nangka	53,57	Leungsir	88,89
	none	0	none	0	Rasamala	171,00	Ki Harendong	83,33
1-3	none	0	none	0	Parempeng	52,27	Ganitri	76,19
	none	0	none	0	Puspa	52,09	Trembesi	61,80
	none	0	none	0	Ki Damar	95,00	Ganitri	66,67
	none	0	none	0	Trembesi	96,67	Ganitri	61,80
	none	0	none	0	Mara	67,61	Ganitri	75,00

Note:
*Seedlings: a woody plant with a height/ tall < 150 cm; Saplings: a woody plant with a height> 150 cm, trunk diameter < 10 cm; Poles: a woody plant with a diameter of 10 cm - 20 cm; Trees: woody plant with diameter > 20 cm.
**Afrika (*Maesopsis eminii*), Ganitri (Elaeocarpus angustifolius), Waru Lot (*Hisbiscus decasperum*), Jati Putih (*Gmelina arborea*), Rasamala (*Altingia excelsa*), Sonobrit (*Dalbergia latifolia*), Pinus (*Pinus merkusii*), Akasia (*Acacia auriculiformis*), Puspa (*Scima walicii*), Matoa (*Pometia pinnata*), Beuying (*Ficus hispida*), Kaliandra (*Caliandra calothersus*), Ki Damar (*Agathis damara*), Ki Harendong (*Melastoma malabathricum*), Calik Angin (*Malotus paniculatus*), Nangka (*Arthocarpus heterphyllus*), Mara (*Macaranga tanarius*), Manglid (*Manglietia glauca*), Mahoni (*Swietenia machrophylla*), Parempeng (*Croton argyratus*)



a b c

Fig. 1. Horizontal canopy structure (a & b) and vertical canopy structure (c) of Trees stand age seven years revegetation in reclamation area of gold-mining Pongkor

Land cover improvement & biodiversity

Revegetation of ex-mining reclamation land not only increased land surface cover with tree crowns and understory plants but also increased flora and fauna biodiversity. The emergence of understory plants with various flowers encouraged the emergence of insects and birds, which acted as seed distributors and assisted crossbreeding in reproduction. The increasingly closed land surface increased humidity and reduced soil temperature, which increased soil organisms' activity (Komara et al., 2018; Salim et al., 2020). Another essential role of soil organisms is decomposer, which can increase the decomposition process of organic biomass or litter from revegetation plants. Complete decomposition encourages improvements in the physical and chemical properties of the soil to support plant growth.

To understand the possibility of the plant's role in stabilizing the heavy metal of tailing, several plant tissue of woody plants were observed the Pb content. AMF application increased Pb content by almost 50% within the stem of *Antocephalus cadamba* seedling (Setyaningsih et al., 2017), while application of Dark Septate Endophyte (DSE) increased chlorophyll content of *Jatropa curcas* 33% in gold tailing (Marfuah et al., 2023). The study highlights the possibility of symbiotic microbes improving reclamation and land remediation.

The ability of revegetation trees and other undergrowth to absorb heavy metal Pb on tailed land and store it mostly in the roots shows that revegetation plants can remediate by stabilizing heavy metals, known as rhizo-stabilizers (Setyaningsih et al., 2018; Akib et al., 2019). The potential of revegetation plants in carrying out phytoremediation gives excellent expectation that cleaning contamination can be done cheaply, safely, and sustainably.

Most local plant species, including rasamala, trembesi, ganitri, and gmelina, could grow on tailings land and degraded mineral soil. This shows that local plants had a high adaptability to the surrounding degraded land. *Cassia siamea*, *Ficus uncinata*, and 18 other woody and non-woody species have been reported to grow well in degraded land (Komara et al., 2018). Several types of plants from the understory group that grow naturally on tailings reclamation land further enrich diversity and show a significant increase in biodiversity in tailings at the same time. These results also support the expectation that reforestation activities in ex-mining reclamation areas can maintain the biodiversity of local tree species.

To sum up, revegetation activities have caused changes slowly, or succession run with certainty, indicated by improvement in land quality, which changed from vacant land to well-covered land. If the series goes well, energy cycles and food cycles occur again. Then, at a particular time, there will be ecosystem stability toward the reconstruction of the new forest again. Vertical strata formed with high biodiversity indicated that reforestation in mining areas was successfully carried out, which led to the return of tropical rainforest ecosystems. This triparty revegetation approach has been applied to several post-mining regions, such as Coal mining in Kalimantan, nickel mining in Sorowako Sulawesi, Indonesia (Setiadi & Setiawan, 2011.), Binungan, Tanjung Redeb, Berau Regency, East Kalimantan (Wulandari et al., 2016), silica & sand mining in west Jawa (Wilarso et al., 2020), tin mining (Perala & Wulandari, 2019).

Reforestation on ex-mining land is very much in line with the SDGs. Selection of plant species for reforestation based on local plants, restoration of biodiversity in reclamation areas from non-planted areas to areas of moderate diversity, and establishment of conservation groups will be in line with SDG 15- Protect, Restore and Promote Sustainable Use of Land Ecosystems, Manage Forests Sustainably, Ending Desertification, Restoring Land Degradation, and Stopping Biodiversity Loss, particularly at 15.1, 15.3, 15.4, 15.5, 15.9, 15.a.1 (United Nation, 2023).

While the following efforts: remediation or cleaning of heavy metal Pb on a regular and sustainable basis by using plants as remediators, utilization of landscape reclamation areas to produce environmental services and nature tourism, forest plants in reclamation areas aged 1-12 have certainly contributed to emission absorption, community participation in both reforestation and utilization of non-timber forest products, in line with SDGs 13- Take rapid action to address climate change and its impacts, especially in (13.2, 13.3, 13.3) (United Nation, 2023).

CONCLUSIONS

Reforestation in ex-mining reclamation areas needs to focus on 3 main approaches: the selection of plant species, the addition of compost, and the application of symbiotic mutualism microbes. Reforestation techniques will likely be replicated in other areas, especially ex-mining areas. Reforestation in ex-mining reclamation areas and increasing the area's biodiversity can also play an essential role in expanding the remediation of heavy metal contamination. Reforestation aligns with efforts to achieve SDGs, especially indicators in No. 13 and 15.

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