JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 12, Number 2 (January 2025):7141-7157, doi:10.15243/jdmlm.2025.122.7141
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Vegetation development and soil conditions in reclaimed areas of former silica mines in Indonesia

Tedi Yunanto[1*], Dadan Wildan[1], Suparno[1], Megawati[2], Natasya Santoso[1]

[1] Bandung Polytechnic of Energy and Mining, Ministry of Energy and Mineral Resources, Jl. Jend. Sudirman No. 623, Bandung, Indonesia
[2] Department of Statistic, IPB University, Dramaga, Bogor, Indonesia

[*]corresponding author: tedi.yunanto@esdm.go.id

Abstract

To restore the function of ex-mining land according to its designation, the ex-mining area must be reclaimed. Ecological dynamics, especially soil conditions and the composition, structure, and biodiversity that occur in reclamation areas, need to be understood so that the reclamation area meets the criteria for the success of mine reclamation. This study aimed to understand the composition, structure, biodiversity, and soil conditions that influence growth in the reclamation area. The research was conducted in a silica mine reclamation area with a 17.8 m radius (r) circular plot (0.1 ha) of 10 plots (±1 ha) for vegetation and 9 points for soil sampling at a depth of 0-30 cm and 30-60 cm. In general, the results of the vegetation inventory show that the tree species recorded are dominated by *Pinus merkusii, Hevea brasiliensis*, and *Enterolobium cyclocarpum* with mean values of diameter, height, and low diversity conditions. The condition of soil physical and chemical properties in the reclamation area at both depths shows low mean values, which can affect the growth rate of plants in the reclamation area. The species of *Schima wallichii* that grow naturally in the reclamation area was found, indicating that the reclamation activities have created a good environment for other tree species to grow naturally. However, enrichment activities need to be carried out to increase biodiversity.

Article history:
Received 30 September 2024
Revised 5 November 2024
Accepted 21 November 2024

Keywords:
composition
diversity
mine reclamation
silica
soil properties
structure

To cite this article: Yunanto, T., Wildan, D., Suparno, Megawati, and Santoso, N. 2025. Vegetation development and soil conditions in reclaimed areas of former silica mines in Indonesia. Journal of Degraded and Mining Lands Management 12(2):7141-7157, doi:10.15243/jdmlm.2025.122.7141.

Introduction

As a developing country, Indonesia still relies on the exploitation of natural resources for national income (Wahyudi and Palupi, 2022). Mining commodities are exploited natural resources (Ishmah et al., 2020), such as silica mining in Sukabumi Regency, West Java Province, Indonesia. Environmental impacts due to mining include landscape changes, mining pits (voids), decreased biodiversity of flora and fauna, and changes in soil conditions (Sonter et al., 2018; Leila et al., 2020; Rehman et al., 2021; Sakellari et al., 2021; Yuningsih et al., 2021; Mulenga, 2022; Christian et al., 2023; Zhao et al., 2023; Widjanarko and Gultom, 2024). To reduce environmental damage caused by mining activities in the exploration and exploitation stages, the former mining area must be reclaimed (Šofranko et al., 2020; Yunanto et al., 2022; Pambudi et al., 2023). The form of reclamation of silica commodity mining activities carried out in Sukabumi District, West Java Province, Indonesia, is to become an Educational Forest Park; therefore, the former mining area is planted with perennials/forest plants. The selection of tree species and the application of appropriate tree-planting techniques are key to the success of these reclamation activities (Yunanto et al., 2019; Pratiwi et al., 2021). Reclamation into forest areas not only aims to improve unstable land conditions and reduce soil erosion but also aims in the long term to improve forest ecosystems related to

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

microclimate, wildlife biodiversity, natural vegetation biodiversity, and soil conditions (Šofranko et al., 2020; Hayati et al., 2021; Lestari et al., 2022; Waitkus, 2022; Yunanto et al., 2022; Mikroutsikos et al., 2023; Nutayla et al., 2023; Zine et al., 2023). In addition, in Indonesia, reclamation activities are also said to be successful if they meet the criteria for successful reclamation according to laws and regulations (Yunanto et al., 2021; Rosikin et al., 2023).

In general, succession can be divided into two types, namely primary succession and secondary succession. The difference between these two types of succession lies in the initial conditions of the succession habitat. Primary succession can be caused by disturbances such as volcanoes, earthquakes, landslides, floods, or fires, where these disturbances result in the loss of soil and organisms, leaving only bare areas of rock, silt, gravel, or sand. Secondary succession is caused by hurricanes, avalanches, insect outbreaks, deforestation, or fires that leave the soil intact. Seeds, spores, and plant roots are still present. Areas that begin with secondary succession will usually reach the next stage faster than primary succession. The number and species of plants that survive often depend on the depth and condition of the soil. Mining activities in forest areas result in overall soil and plant disturbance. Mining reclamation is a form of primary succession, aiming to restore the forest to its original state over a very long period (Pawul et al., 2022).

In general, mine reclamation activities are carried out through two stages, namely land recontouring and revegetation (Yunanto et al., 2021; Pambudi et al., 2023). The species of plants planted in the reclamation area of the former silica mine are *Pinus merkusii*, *Hevea brasiliensis*, and *Enterolobium cyclocarpum*. Reclamation activities were carried out in 2013. The soil used in the study area is a mixture of topsoil and subsoil. The soil is very important as a growing medium and is the key to the success of reclamation activities so that it meets the success criteria. Therefore, this study aimed to understand the soil conditions in the reclaimed area and its effect on stand structure, composition, biodiversity, and natural regeneration.

Materials and Methods

Study area

The study was conducted in the post-mining area of a silica mining company in Sukabumi Regency, West Java Province, Indonesia. The silica mining activities have been carried out for 35 years, and reclamation activities were carried out in 2013. Due to the limited amount of soil, the reclamation activities were carried out using a potting system, i.e., topsoil and subsoil were applied only to the plant holes, which measured 1 m x1 m x 1 m (Figure 1). The species of plants planted in the former mining area are *Pinus merkusii*, *Hevea brasiliensis*, and *Enterobilium cyclocarpum*. The reclamation activities in the former mining area are intended to develop the Educational Forest Park.

Figure 1 Application of topsoil to plant holes (Source: IPB University, 2013).

Data collection and analysis

The research activities were conducted in 2022, so the reclamation area is ± 9 years old. Vegetation analysis for stand structure, composition, biodiversity, and natural regeneration was conducted using modified circular plots with a radius of r = 17.8 m or approximately 0.1 ha. A total of 10 plots (± 1 ha), which is the minimum plot size that can be used for silvicultural research (Lamprecht, 1989) (Figure 2 and Table 1).

Figure 2. Measurement plot of vegetation analysis.

Table 1. Coordinate point sampling.

Plot number	Coordinate point	
	South latitude	East longitude
1	6°55'16"S	106°47'6"E
2	6°55'15"S	106°47'5"E
3	6°55'14"S	106°47'10"E
4	6°55'14"S	106°47'11"E
5	6°55'21"S	106°48'26"E
6	6°55'38"S	106°52'27"E
7	6°54'24"S	106°46'46"E
8	6°52'19"S	106°45'56"E
9	6°54'34"S	106°47'3"E
10	6°54'46"S	106°47'8"E

All trees with diameter at breast height (DBH, 1.3 m) ≥10 cm DBH within a radius of r = 17.8 m were recorded by species name, and their total diameter and height were measured. For soil, nine points were taken,

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

where each point was taken at two depths, namely 0-30 cm and 30-60 cm depth. Some of the soil properties analyzed included texture, conductivity, pH, carbon, nitrogen, C/N ratio, cation exchange capacity (CEC), base saturation (BS), etc.

Sampling methods for vegetation and soil were randomized to obtain representative data with the same probability of inclusion. Measurement results were further processed using Microsoft Excel, Statistica Ver 12 program, and R program.

Result and Discussion

Sampling accuracy

The species-area curve is one approach that can be used to determine the minimum representative area of a given community and the minimum plot size for plant community surveys (Lamprecht, 1989). Vegetation community analysis should continue until the increase in new species found in subsequent plots is at least below 10% of the number of species found in all plots (Cain, 1938; Lamprecht, 1989). In this study, the species-area curve was based on all tree species with DBH ≥10 cm. The results of the vegetation inventory show that an increase in the number of tree species present in the reclamation area with a total increase in plant species of <10% has occurred from plot 5 to plot 6 (plot size 5,000-6,000 m^2). This confirms that the plot design used in this study is suitable for vegetation inventory in ex-mining areas. The species-area curve can be seen in detail in Figure 3.

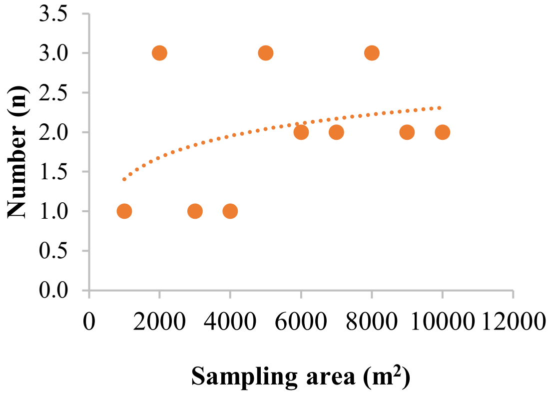

Figure 3. Species-area curve.

The accuracy of sampling was further assessed based on the standard deviation error of the mean basal area (Table 2). The smaller the standard deviation error of the mean basal area, the more the plots used were representative of the entire population. In this study, the calculated standard deviation of the mean basal area for both plots and each plot was based on trees with DBH ≥10 cm. The standard deviation values of all plots, plot 1, plot 3, plot 4, plot 5, plot 6, plot 7 and plot 8 were below 10%, namely 9.23%, 4.94%, 4.66%, 5.13%, 4.79%, 7.73%, 5.53% and 6.97% respectively. The standard deviation of plot 2, plot 9, and plot 10 is more than 10%, namely 12.78%, 10.26%, and 11.42%, which is likely due to differences in plant species that cause variations in diameter growth rates. The mean standard deviation value of the basal area is about 10%, which is to the accuracy requirements for conventional vegetation analysis (Zöhrer, 1980).

Table 2. Mean basal area and standard deviation for all plots and each plot.

Plot number	**Basal area mean ± Standard deviation**	**Standard deviation (Sg****; %)**
Plot 1 (0.1 ha)	11.15 ± 0.09	4.94
Plot 2 (0.1 ha)	13.43 ± 0.25	12.78
Plot 3 (0.1 ha)	19.17 ± 0.11	4.66
Plot 4 (0.1 ha)	19.44 ± 0.13	5.13
Plot 5 (0.1 ha)	16.80 ± 0.10	4.79
Plot 6 (0.1 ha)	15.21 ± 0.16	7.73
Plot 7 (0.1 ha)	20.97 ± 0.14	5.53
Plot 8 (0.1 ha)	21.52 ± 0.18	6.97
Plot 9 (0.1 ha)	14.01 ± 0.20	10.26
Plot 10 (0.1 ha)	7.00 ± 0.12	11.42
All Plots (ha)	15.87 ± 0.16	9.23

Diameter (DBH), density, and basal area

The calculated mean diameters were based on the arithmetic and quadratic (basal area) mean diameter formulas (Table 3). In general, the mean diameter of trees in the reclamation area across all plots was 18.70 cm (arithmetic) and 18.99 cm (quadratic). The arithmetic and quadratic mean diameters from plot 1 to plot 9 ranged between 17.00 cm-19.00 cm and 18.00 cm and 20.00 cm, respectively. These values were higher than the diameter value of plot 10. Density and basal area parameters were calculated based on tree DBH ≥10 cm (Table 4). The density and basal area for all plots were 599 trees/ha and 15.87 m^2/ha, respectively. The highest density for each plot was in plot 8 (72 trees/0.1 ha), while the lowest was in plot 1 (35 trees/0.1 ha). The plot with the highest basal area was plot 8 (21.52 m^2/0.1 ha), while the lowest was plot 10 (7.00 m^2/0.1 ha). According to legislation, mining companies must plant trees with a spacing of 4 m x 4 m (625 trees/ha). However, the density in all plots was 559 trees/ha, still below 625 trees/ha. This condition

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

may be due to the death of seedlings that were not replanted.

Table 3. Mean arithmetic and quadratic diameters (DBH ≥10 cm).

Plot number	n	Arithmetic mean ± Standard deviation (cm)	Quadratic mean (cm)
Plot 1 (0.1 ha)	1	19.90 ± 3.11	20.14
Plot 2 (0.1 ha)	1	17.90 ± 6.05	18.88
Plot 3 (0.1 ha)	1	19.33 ± 3.77	19.69
Plot 4 (0.1 ha)	1	19.41 ± 4.04	19.82
Plot 5 (0.1 ha)	1	18.53 ± 3.70	18.88
Plot 6 (0.1 ha)	1	18.41 ± 5.22	19.12
Plot 7 (0.1 ha)	1	19.42 ± 4.65	19.96
Plot 8 (0.1 ha)	1	18.73 ± 5.51	19.51
Plot 9 (0.1 ha)	1	17.33 ± 6.09	18.35
Plot 10 (0.1 ha)	1	13.33 ± 4.06	13.92
All Plots (ha)	10	18.70 ± 4.99	18.99

Table 4. Mean tree density and basal area (DBH ≥10 cm).

Plot Number	n	Density	Basal area mean ± Standard deviation
Plot 1 (0.1 ha)	1	35	11.15 ± 0.09
Plot 2 (0.1 ha)	1	48	13.43 ± 0.25
Plot 3 (0.1 ha)	1	63	19.17 ± 0.11
Plot 4 (0.1 ha)	1	63	19.44 ± 0.13
Plot 5 (0.1 ha)	1	60	16.80 ± 0.10
Plot 6 (0.1 ha)	1	53	15.21 ± 0.16
Plot 7 (0.1 ha)	1	67	20.97 ± 0.14
Plot 8 (0.1 ha)	1	72	21.52 ± 0.18
Plot 9 (0.1 ha)	1	53	14.01 ± 0.20
Plot 10 (0.1 ha)	1	46	7.00 ± 0.12
All Plots (ha)	10	559	15.87 ± 0.16

In general, the reclamation area is planted with *Pinus merkusii*, followed by *Hevea brasiliensis* and *Enterolobium cyclocarpum*. The mean diameter of the three species can be said to be ± 18.99 cm. According to Patabang et al. (2014), the mean diameter value of *Pinus merkusii* in Tana Toraja Regency at the age of 10 years is 17 cm, and 28.44 cm for the age of 18 years still in the same area (Patabang and Hardjanto, 2021). Meanwhile, according to Nugrahanto et al. (2022), the mean diameter of *Pinus merkusii* species at the age of 11 years for progeny from Sumedang, Jember, and East Java landraces was 23.33 cm, 22.57 cm, and 22.31 cm, respectively. However, these values are the mean diameter of *P. merkusii* planted not in the former mining area. For the *H. brasiliensis* species, the mean diameter at the age of 11 years planted in a non-mine area was 20.9 cm (Oktofian et al., 2023) and 23.7 cm at the age of 20 years (Hytönen et al., 2019). As for *E. cyclocarpum*, the mean diameter at the age of 9 years was 30.84 cm and 28.80 cm at the age of 6 years. This value is the mean value of *E. cyclocarpum* species planted in former coal mining areas (Amanah and Yunanto, 2019). The difference in mean diameter values can be caused by differences in planting age and soil conditions.

Diameter distribution

In this study, diameter distribution was calculated from the number of trees with DBH class ≥10 cm (DBH interval = 5 cm for all plots, and DBH interval = 3 cm for each plot). In general, the graph formed from the relationship between the number of trees and the diameter class is divided into three forms, namely an inverted J-shape, an imperfect normal distribution curve, and a perfect normal distribution curve (Figure 4 and Figure 5). The distribution of tree diameters can describe the forest structure or the canopy layers that make up a forest stand. In natural or unaged forests, the forest structure resembles an inverted J, and in plantations or aged forests, the forest structure is bell-shaped or has a normal distribution curve with the largest number of trees in the middle diameter range (Safitri et al., 2020; Kara, 2021).

This diameter distribution pattern can indicate whether the forest condition is within the normal range or has been disturbed. The graphs for all plots, plot 2, plot 9, and plot 10, show an inverted J-shape graph, where the total number of individuals decreases with increasing DBH. Among the four inverted J-shape graphs, the graph on plot 10 has the highest correlation coefficient (r), which is r = 0.9758. Meanwhile, the lowest r value on the inverted J-shape graph is on plot 2, which is r = 0.6865. Graphs with imperfect normal distribution curve shapes are owned by plot 1, plot 6, and plot 8. Graphs with perfect normal distribution curve shapes are owned by plot 3, plot 4, plot 5, and plot 7. Among the four perfect normal distribution curve shape graphs, the graph in plot 3 has the highest correlation coefficient (r), which is r = 0.838. In

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

comparison, the lowest r value on the imperfect normal distribution curve shape graph is on plot 5, which is r = 0.6856. All four plots have a bell-shaped diameter distribution or perfect normal distribution (normal graph), where the number of small-diameter and largest-diameter trees are in a balanced composition. Albasri et al. (2023) stated that a normal stand structure will follow an inverted J curve pattern, where the population of stands with smaller dimensions (small diameter) is more in density (trees/ha) compared to those with large diameter. According to de Liocort's law, a natural forest stand is normal if the curve forms an inverted J. A diameter class distribution in a stand that forms an inverted J curve is an indicator of a stable and growing stand. Such stands have more trees in smaller classes, indicating continuous recruitment for natural succession (Gonçalves et al., 2017; Staporn et al., 2022).

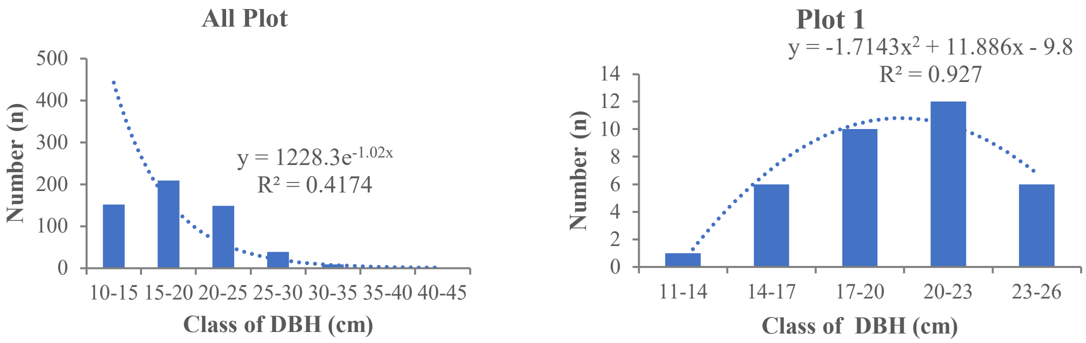

Figure 4. Diameter distribution for all plots and plot 1.

Stand height

The mean total height for all plots was 11.87 m for arithmetic and 12.25 m for Lorey's (Table 5). Plot 5 had the highest arithmetic mean compared to the other plots at 13.28 m. As for the mean Lorey's height, plot 2 had the greatest mean height, at 14.18 m. Plot 10 had the lowest mean height for both arithmetic and Lorey's compared to the other plots at 10.51 m for arithmetic and 11.23 m for Lorey's.

As for plant height, the mean height value of the three species of plants planted can be said to be ± 12.25 m. The mean value of *Pinus merkusii* tree height in Tana Toraja Regency at the age of 10 years and 15 years is 16.58 m and 26.92 m, respectively, and 23.77 m for the age of 18 years still in the same area (Patabang et al., 2014; Patabang and Hardjanto, 2021). Meanwhile, according to Nugrahanto et al. (2022), the mean height of *Pinus merkusii* species at the age of 11 years for progeny from Sumedang, Jember, and East Java landraces were 15.31 m, 14.83 m and 14.58 m, respectively. However, these values are the mean height of *P. merkusii* planted not in the former mining area.

For the *H. brasiliensis* species, the mean height at the age of 11 years planted in non-mined areas was 10.62 m (Oktofian et al., 2023) and 19.8 m at the age of 20 years (Hytönen et al., 2019). As for *E. cyclocarpum*, the mean height at the age of 9 years was 15.87 m, and 12.77 m at the age of 6 years. These are the mean values of *E. cyclocarpum* species planted in former coal mining areas (Yunanto, 2018; Amanah and Yunanto, 2019). Similar to the mean diameter, the difference in mean height values can be caused by differences in planting age and soil conditions.

Table 5. Average stand height of all plots and each plot (DBH ≥10 cm).

Plot number	n	Arithmetic mean ± Standard deviation (m)	Lorey's mean (h_g; m)
Plot 1 (0.1 ha)	1	12.69 ± 1.34	12.86
Plot 2 (0.1 ha)	1	12.71 ± 2.00	14.18
Plot 3 (0.1 ha)	1	12.20 ± 1.47	12.52
Plot 4 (0.1 ha)	1	11.44 ± 1.49	11.86
Plot 5 (0.1 ha)	1	13.28 ± 1.97	12.03
Plot 6 (0.1 ha)	1	11.23 ± 1.76	11.88
Plot 7 (0.1 ha)	1	11.30 ± 1.36	11.70
Plot 8 (0.1 ha)	1	12.07 ± 1.33	12.50
Plot 9 (0.1 ha)	1	11.28 ± 1.08	11.71
Plot 10 (0.1 ha)	1	10.51 ± 1.63	11.23
All Plot (ha)	10	11.87 ± 1.67	12.25

Important Value Index (IVI)

In general, the results of the vegetation inventory show that the tree species recorded are dominated by pine (*Pinus merkusii*; Table 6). In addition, the dominant species planted were rubber (*Hevea brasiliensis*) and albasia (*Enterolobium cyclocarpum*). The albasia

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

species is a fast-growing species planted by mining companies, which is associated with azotobacter bacteria to fix nitrogen from the air (Pratiwi et al., 2020; de Faria et al., 2022). In addition, there are “puspa” (*Schima wallichii*) species that grow naturally in the reclamation area and can be found in plots 2, 5, 6, 7, and 8. This shows that reclamation activities have created a good environment for other tree species to grow naturally in the reclamation area (Pambudi et al., 2023).

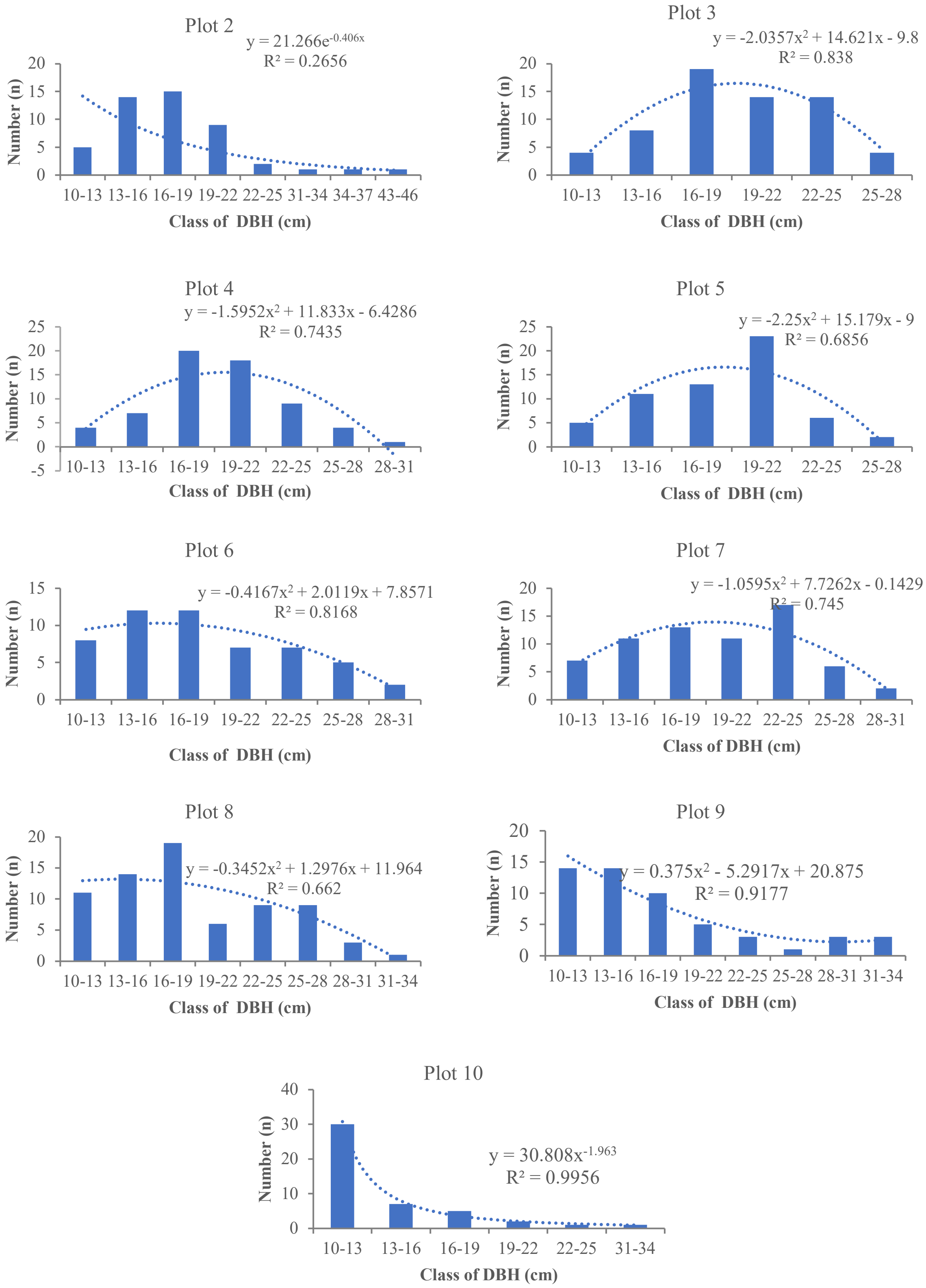

Figure 5. Diameter distribution for plot 2-plot 10.

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

Table 6. Important Value Index (IVI).

No	Species Name	Family	Density (tree/ha) (D)	Frequency (F)	Basal Area (m^2/ha) (D)	Relative Density (%)	Relative Frequency (%)	Relative Dominance (%)	IVI (%)
Plot 1									
1	*P. merkusii*	Pinaceae	350	1	11.15	100	100	100	300
Total			**350**	**1**	**11.15**	**100**	**100**	**100**	**300**
Plot 2									
1	*P. merkusii*	Pinaceae	429	1	9.72	89.58	33.33	72.37	195.29
2	*E. cyclocarpum*	Fabaceae	30	1	3.40	6.25	33.33	25.30	64.88
3	*S. wallichii**	Theaceae	20	1	0.31	4.17	33.33	2.33	39.83
Total			**479**	**3**	**13.43**	**100**	**100**	**100**	**300**
Plot 3									
1	*P. merkusii*	Pinaceae	629	1	19.17	100	100	100	300
Total			**629**	**1**	**19.17**	**100**	**100**	**100**	**300**
Plot 4									
1	*P. merkusii*	Pinaceae	629	1	19.44	100	100	100	300
Total			**629**	**1**	**19.44**	**100**	**100**	**100**	**300**
Plot 5									
1	*E. cyclocarpum*	Fabaceae	20	1	0.31	3.33	33.33	1.86	38.53
2	*P. merkusii*	Pinaceae	549	1	15.65	91.67	33.33	93.10	218.10
3	*S. wallichii**	Theaceae	30	1	0.85	5.00	33.33	5.03	43.37
Total			**599**	**3**	**16.80**	**100**	**100**	**100**	**300**
Plot 6									
1	*P. merkusii*	Pinaceae	499	1	14.79	94.34	50.00	97.22	241.56
2	*S. wallichii**	Theaceae	30	1	0.42	5.66	50.00	2.78	58.44
Total			**529**	**2**	**15.21**	**100**	**100**	**100**	**300**
Plot 7									
1	*P. merkusii*	Pinaceae	659	1	20.86	98.51	50.00	99.51	248.02
2	*S. wallichii**	Theaceae	10	1	0.10	1.49	50.00	0.49	51.98
Total			**669**	**2**	**20.97**	**100**	**100**	**100**	**300**
Plot 8									
1	*H. brasiliensis*	Euphorbiaceae	469	1	9.54	65.28	33.33	44.36	142.97
2	*P. merkusii*	Pinaceae	240	1	11.85	33.33	33.33	55.07	121.74
3	*S. wallichii**	Theaceae	10	1	0.12	1.39	33.33	0.57	35.29
Total			**719**	**3**	**21.52**	**100**	**100**	**100**	**300**

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

No	Species Name	Family	Density (tree/ha) (D)	Frequency (F)	Basal Area (m^2/ha) (D)	Relative Density (%)	Relative Frequency (%)	Relative Dominance (%)	IVI (%)
Plot 9									
1	*H. brasiliensis*	Euphorbiaceae	459	1	9.75	86.79	50.00	69.56	206.35
2	*P. merkusii*	Pinaceae	70	1	4.27	13.21	50.00	30.44	93.65
Total			**529**	**2**	**14.01**	**100**	**100**	**100**	**300**
Plot 10									
1	*H. brasiliensis*	Euphorbiaceae	439	1	5.81	95.65	50.00	83.05	228.70
2	*P. merkusii*	Pinaceae	20	1	1.19	4.35	50.00	16.95	71.30
Total			**459**	**2**	**7.00**	**100**	**100**	**100**	**300**
All Plot									
1	*E. cyclocarpum*	Fabaceae	5	0.20	0.37	0.89	10.00	2.34	13.23
2	*P. merkusii*	Pinaceae	407	1.00	12.81	72.76	50.00	80.71	203.46
3	*S. wallichii**	Theaceae	10	0.50	0.18	1.78	25.00	1.14	27.92
4	*H. brasiliensis*	Euphorbiaceae	137	0.30	2.51	24.43	15.00	15.82	55.25
Total			**560**	**2.00**	**15.87**	**100**	**100**	**100**	**300**

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

Diversity Index

Based on the analysis results, the mean tree-level diversity index has a low diversity index value for both all plots and each plot (H' <1.0; Yuningsih et al., 2021) (Table 7). The plot with the highest H' value was plot 8, H' = 0.70, while the plots with the lowest H' values were plots 3 and 4, H' = 0.00 each. Based on the Shannon Evennes (J') value, plot 2 has the highest J' value, J' = 0.58, which means there is one species that dominates the community. While the highest Simpson index (1-D) is plot 8, 1-D = 0.4632, which indicates that plot 8 has a medium diversity index. The condition of soil properties can cause the low diversity of flora in the reclamation area. Villa et al. (2023) state that soil fertility is directly proportional to the biodiversity of both flora and fauna. In addition, the diversity of flora and fauna is also directly proportional to the age of reclamation. With the increasing age of mine reclamation, the value of diversity will also increase (Yunanto, 2018). This shows that natural regeneration and growth can be created in reclamation areas (Haigh et al., 2020; Lewis and Rosales, 2020). In addition, because natural processes are highly linear with time, the reclamation process requires human intervention, including the use of technology (Villa et al., 2013).

Table 7. Shannon Wiener (H‘), Shannon Evenness (J’) and Simpson (D) indices of tree level (height (h) 1.30 m and DBH ≥10 cm).

Plot number	Species (n)	Shannon Wiener Index (H')	Shannon Evenness (J')	Simpson Index (1-D)
Plot 1 (0.1 ha)	1	0.00	0.00	0.0000
Plot 2 (0.1 ha)	3	0.40	0.58	0.1922
Plot 3 (0.1 ha)	1	0.00	0.00	0.0000
Plot 4 (0.1 ha)	1	0.00	0.00	0.0000
Plot 5 (0.1 ha)	3	0.34	0.31	0.1564
Plot 6 (0.1 ha)	2	0.22	0.20	0.1070
Plot 7 (0.1 ha)	2	0.08	0.07	0.0294
Plot 8 (0.1 ha)	3	0.70	0.54	0.4632
Plot 9 (0.1 ha)	2	0.39	0.56	0.2297
Plot 10 (0.1 ha)	2	0.18	0.16	0.0834
All Plot (ha)	4	0.69	0.38	0.4113

Growth differences between plots

Using Kruskal-Wallis statistical analysis, growth differences of all plots were observed. The data used to look at differences in growth between plots were height and diameter parameters. The results in Table 8 show that diameter and height parameters significantly differ at the 95% confidence level. The hypothesis formulation in the Kruskal-Wallis test is as follows:

H_0 : there is no significant difference in plant height and diameter between plots
H_1 : there is at least one pair of significantly different plots

Table 8. Kruskal-Wallis test result.

Kruskal-Wallis Test		
Parameter	***p-value***	**Significance Test**
Diameter	8.06e-14*	significantly different
Height	1.01e-15*	significantly different

*Significantly different at 5%.

From the results of the test statistics, the p-value of plant diameter and height is smaller than α, so the null hypothesis (H_0) is rejected. So, with a confidence level of 95%, it can be concluded that there was at least one pair of plots that were significantly different in both plant diameter and height. To determine which plots have significant differences, a further test or Post Hoc test is carried out using the Wilcoxon test. From this test, the pairs of plots are presented in Table 9 for diameter and Table 10 for height.

The Wilcoxon test results in Table 9 show the differences in tree diameter growth between the pairs of plots. Plot 1 had a significant difference from plots 2, 9, and 10 due to the greater difference in mean values between these plot pairs compared to other plot pairs. Plot 2 is significantly different from plots 3, 4, 5, 6, 7, 9 and 10. On the other hand, plots 3, 4, 5, and 7 have significant differences with plot 9 and plot 10. Meanwhile, plots 6, 8, and 9 only have a significant difference from plot 10. The Wilcoxon test results (Table 10) show the difference in tree height growth between some pairs of plots. It can be seen that plot 1, plot 2, and plot 3 had significant differences from other plots in tree diameter growth. This could be due to the different responses of tree diameter and height growth to their surroundings, such as the environment, soil elements, and others. Diameter and height growth in reclaimed areas are more influenced by soil chemical properties such as pH, CEC, organic C, total N, and available P_2O_5 than soil physical properties (Iskandar et al., 2022; Yunanto et al., 2022).

In addition, the Wilcoxon test on tree diameter and height growth for plot 10 was almost significantly different from all other plots. It can also be seen that the mean difference value paired with plot 10 has a larger value. Meanwhile, significant differences were

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

found in plots with negative mean difference values. For instance, tree height in plots 1, 2, and 3, based on the Wilcoxon test, showed significant differences. The negative mean difference test results showed that the mean tree height in plot 5 (the compared plot) was consistently higher than plots 1, 2, and 3, respectively.

Table 9. Results of mean difference test of tree diameter for each plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Plot 1										
Plot 2	2*									
Plot 3	0.58	-1.42*								
Plot 4	0.49	-1.51*	-0.08							
Plot 5	1.38	-0.62*	0.80	0.89						
Plot 6	1.50	-0.50	0.92	1.01	0.12					
Plot 7	0.48	-1.52*	-0.09	-0.01	-0.89	-1.01				
Plot 8	1.18	-0.82	0.60	0.69	-0.20	-0.32	0.69			
Plot 9	2.58*	0.57	2*	2.08*	1.20*	1.08	2.09*	1.40		
Plot 10	6.58*	4.57*	6*	6.08*	5.20*	5.08*	6.09*	5.40*	4*	

*Significant at a 95% confidence level based on the Wilcoxon test.

Table 10. Results of mean difference test of tree height for each plot.

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8	Plot 9	Plot 10
Plot 1										
Plot 2	-0.03									
Plot 3	0.49	0.52								
Plot 4	1.25*	1.28*	0.76*							
Plot 5	-0.59*	-0.56*	-1.08*	-1.85						
Plot 6	1.47*	1.49*	0.97*	0.21	2.06					
Plot 7	1.39*	1.42*	0.90*	0.14	1.98	-0.07				
Plot 8	0.60*	0.63	0.11	-0.65*	1.19	-0.86*	-0.79*			
Plot 9	1.41*	1.44*	0.92*	0.15	2.00	-0.06	0.02	0.81*		
Plot 10	2.18*	2.21*	1.69*	0.93*	2.77*	0.72	0.79*	1.58*	0.77*	

*Significant at a 95% confidence level based on the Wilcoxon test.

Soil condition in the reclamation area

Soil analysis results (Table 11 and Table 12) show that, in general, soil texture in the reclamation area has high mean clay content values for both the 0-30 cm (48.11%) and 30-60 cm (50.78%) depths. The pH value in the reclaimed area has a mean pH value of <4.5, indicating that it is highly acidic. Likewise, CEC values fall into the low category for both 0-30 cm (14.51 meq/100 g) and 30-60 cm (14.56 meq/100 g) depths. In general, soil chemical properties for the two depths are in the very low and low categories, except for the base saturation value which is in the medium category. The results of the analysis of soil physical and chemical properties at the two depths in the reclamation area can be said to affect the growth of the diameter of the soil. Furthermore, to evaluate the content of the soil elements in the area, the evaluation was conducted by applying Principal Component Analysis (PCA) to the collected soil samples. PCA was used to identify the main patterns in soil element variation at different depths for each sample. Figure 6 and Figure 7 are scree plots for each depth sample illustrating the distribution of soil element variation in the data.

Based on the importance of the components, it can be seen that the first two PCs have the highest values for the proportion of variation at each sample depth. This indicates a significant proportion of the variance of the soil elements, with the principal components explaining about 34.2% and 32.7% of the total variance. This was followed by the second principal component with proportions of approximately 25.7% and 23.4% of the total variance. These results indicate the high importance of the two principal components in explaining variations in soil structure and characteristics at the depths analyzed.

The variable contributions to each principal component are presented in Figure 8 and Figure 9. The results presented in Figures 8 and 9 show that the soil elements at a depth of 0-30 cm, for the elements pH (H_2O), pH (KCl), Ca (cmol/mg), Mg (cmol/mg), clay, H (cmol/mg), Al (cmol/mg) and N have high contribution values indicating that these elements have a good contribution in representing the main components. In this case, the element is placed close to the circle on the correlation circle. The sand (%) and C/N ratio have low contribution values, which means these elements are less important for the main component.

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

Table 11. Results of the analysis of physical and chemical properties of soil at a depth of 0-30 cm.

Location	**Depth (0-30 cm)**																	
	Sand (%)	**Silt (%)**	**Clay (%)**	**pH (H_2O)**	**pH (KCl)**	**C**	**N**	**C/N Ratio**	**P_2O_5 (ppm)**	**K_2O (ppm)**	**Ca (cmol/kg)**	**Mg (cmol/kg)**	**K (cmol/kg)**	**Na (cmol/kg)**	**CEC (me/100g)**	**BS (%)**	**Al (cmol/kg)**	**H (cmol/kg)**
Plot 1	51	11	38	4	3.80	0.44	0.04	11	3.1	67	2.89	0.57	0.13	0.41	10.86	37	2.75	0.47
Plot 2	28	23	49	4	3.20	0.36	0.03	12	3.2	96	1.39	0.3	0.19	0.15	13.51	15	6.03	1.44
Plot 3	37	38	25	4	3.10	0.79	0.08	10	11.6	61	1.71	1.51	0.11	0.04	10.88	31	5.45	0.9
Plot 4	3	29	68	5	4.00	1.42	0.11	13	7.6	243	2.37	0.8	0.48	0.12	19.25	20	2.05	0.38
Plot 5	11	28	61	4	3.40	0.19	0.01	19	3.4	43	1.56	0.8	0.08	0.54	17.44	17	6.02	0.82
Plot 6	7	34	59	4	3.00	0.57	0.05	11	2.6	73	1.04	0.44	0.14	0.37	14.26	14	6.14	1.29
Plot 7	22	42	36	3	3.20	1.74	0.14	12	7.4	12	1.67	1.24	0.02	0.02	12.66	23	5.58	1.05
Plot 8	22	35	43	3.9	3.60	0.28	0.03	9	6.8	136	1.32	0.5	0.27	0.06	14.34	15	12.01	1.93
Plot 9	20	26	54	4.6	3.90	0.72	0.06	12	3.9	531	3.57	0.76	1.06	0.07	17.39	31	1.64	0.36
Mean	22.33	29.56	48.11	4.00	3.47	0.72	0.06	12.11	5.51	140.22	1.95	0.77	0.28	0.20	14.51	22.56	5.30	0.96

Table 12. Results of analysis of physical and chemical properties of 30-60 cm depth soil.

Location	**Depth (30-60 cm)**																	
	Sand (%)	**Silt (%)**	**Clay (%)**	**pH (H_2O)**	**pH (KCl)**	**C**	**N**	**C/N Ratio**	**P_2O_5 (ppm)**	**K_2O (ppm)**	**Ca (cmol/kg)**	**Mg (cmol/kg)**	**K (cmol/kg)**	**Na (cmol/kg)**	**CEC (me/100g)**	**BS (%)**	**Al (cmol/kg)**	**H (cmol/kg)**
Plot 1	44	13	43	4.7	4.2	0.45	0.04	11	3.4	48	4.3	0.65	0.08	0.88	10.92	54	1.48	0.35
Plot 2	26	25	49	4.4	3.7	0.32	0.03	11	2.2	13	3.73	0.72	0.02	0.35	15.83	30	3.6	0.46
Plot 3	36	36	28	3.3	3.1	0.73	0.07	10	4.3	47	1.59	1.53	0.09	0.06	10.23	32	5.15	0.87
Plot 4	4	25	71	4.5	3.9	1.24	0.1	12	7.4	68	2.47	0.76	0.13	0.1	19.44	18	2.31	0.36
Plot 5	11	27	62	4.4	3.7	0.16	0.01	16	2.2	51	1.41	0.79	0.1	0.49	16.8	17	3.58	0.28
Plot 6	4	38	58	3.5	3	0.55	0.05	11	3.1	81	1.49	0.67	0.15	0.26	14.81	17	5.72	1.03
Plot 7	22	36	42	3.1	2.9	0.81	0.08	10	3.5	67	1.6	1.84	0.13	0.07	13.6	27	6.01	0.71
Plot 8	22	30	48	3.9	3.5	0.26	0.02	13	3.5	92	1.28	0.6	0.17	0.05	15.1	14	12.11	1.68
Plot 9	20	24	56	4.7	3.9	0.48	0.05	10	3	431	2.32	0.84	0.84	0.09	14.32	29	1.42	0.28
Mean	21.00	28.22	50.78	4.06	3.54	0.56	0.05	11.56	3.62	99.78	2.24	0.93	0.19	0.26	14.56	26.44	4.60	0.67

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

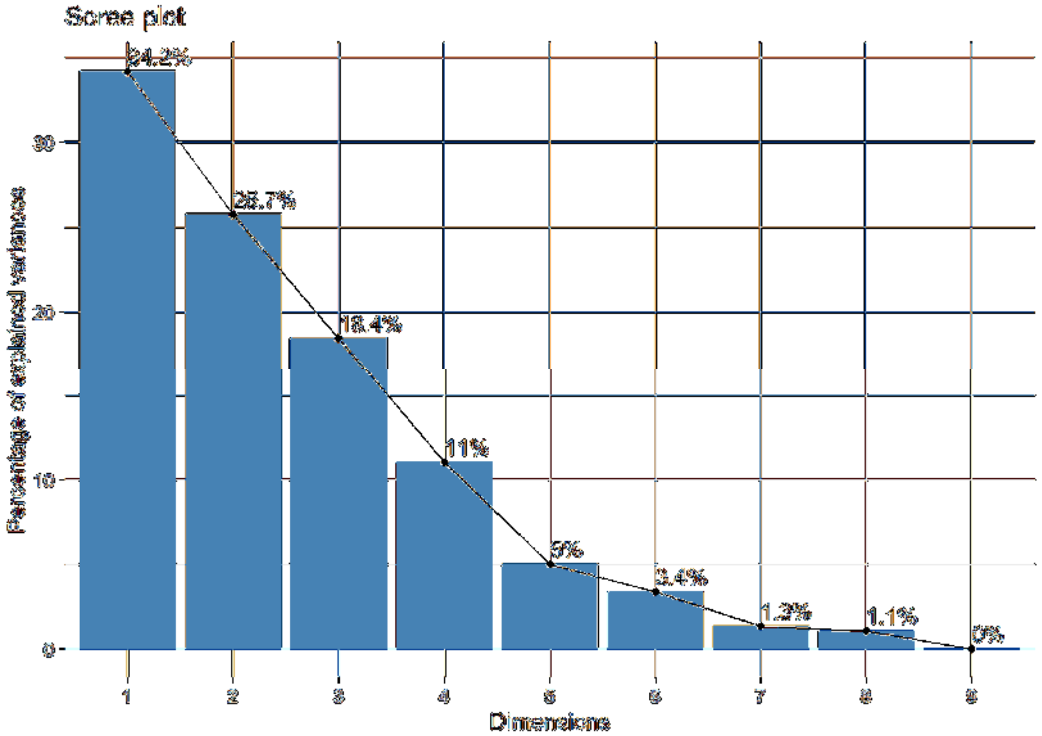

Figure 6. Scree plot depth 0-30 cm.

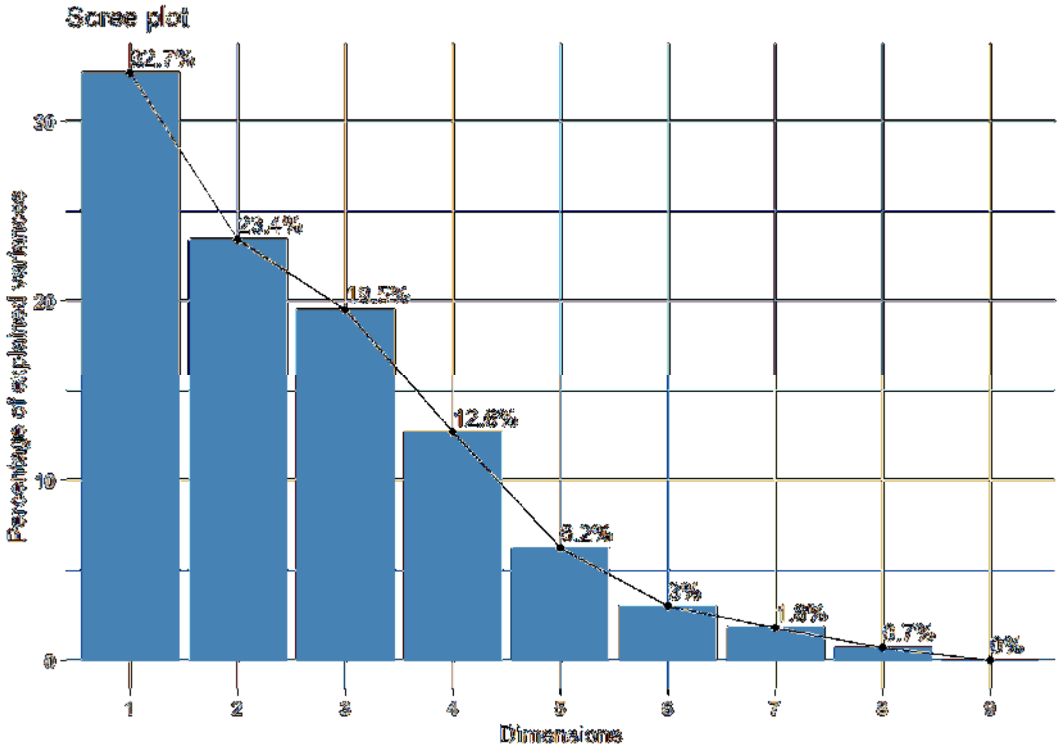

Figure 7. Scree plot depth 30-60 cm.

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

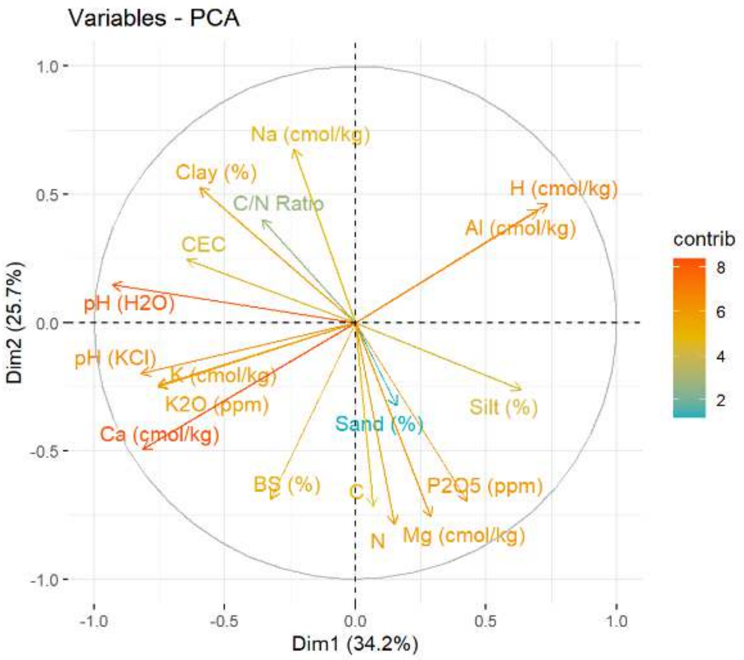

Figure 8. Variables contribution depth 0-30 cm.

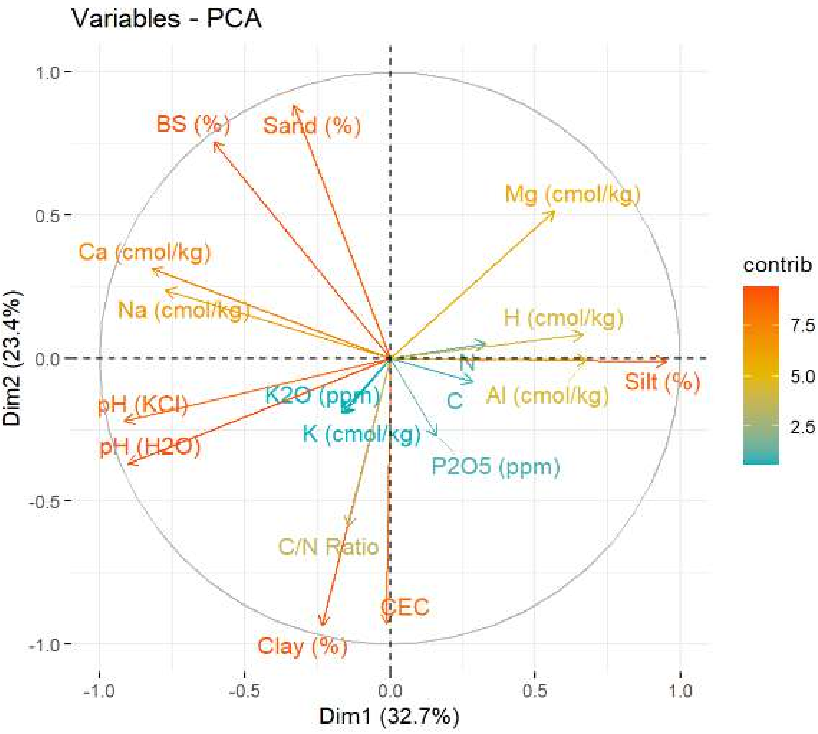

Figure 9. Variables contribution depth 30-60 cm.

While at a depth of 30-60 cm, the soil pH (H_2O), pH (KCl), Ca (cmol/mg), Mg (cmol/mg), clay, and H (cmol/mg) show the same results as the depth of 0-30 cm. This means they have high contribution values to represent the main components. Unlike the elements Al (cmol/mg) and N, which have contribution values at a depth of 0-30 cm but low at a depth of 30-60 cm. This indicates that the further these two elements are from the soil surface, the lower their contribution to the main component. This is different from the element sand (%), where the farther the element is from the soil surface, the higher the contribution to the main component is.

On the other hand, the element base saturation has the same characteristics as sand (%), whereas the elements K_2O, K (cmol/mg), and P_2O_5 (ppm) are considered not too important in representing the main components. To describe the relationship between soil elements at each observation point (plot), see Figure 10 and Figure 11.

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

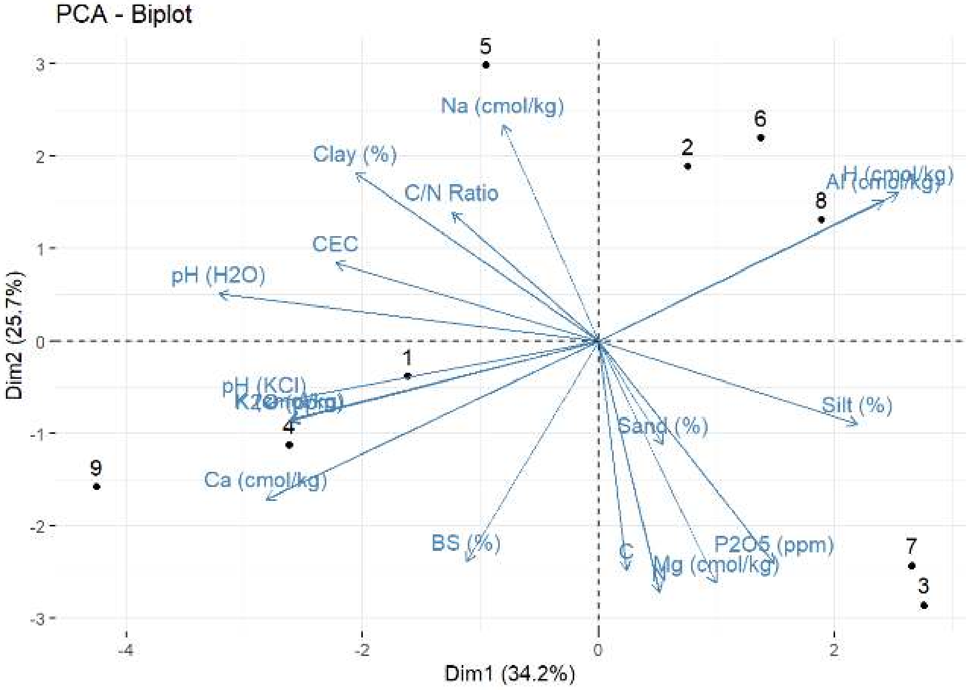

Figure 10. Biplot depth 0-30 cm.

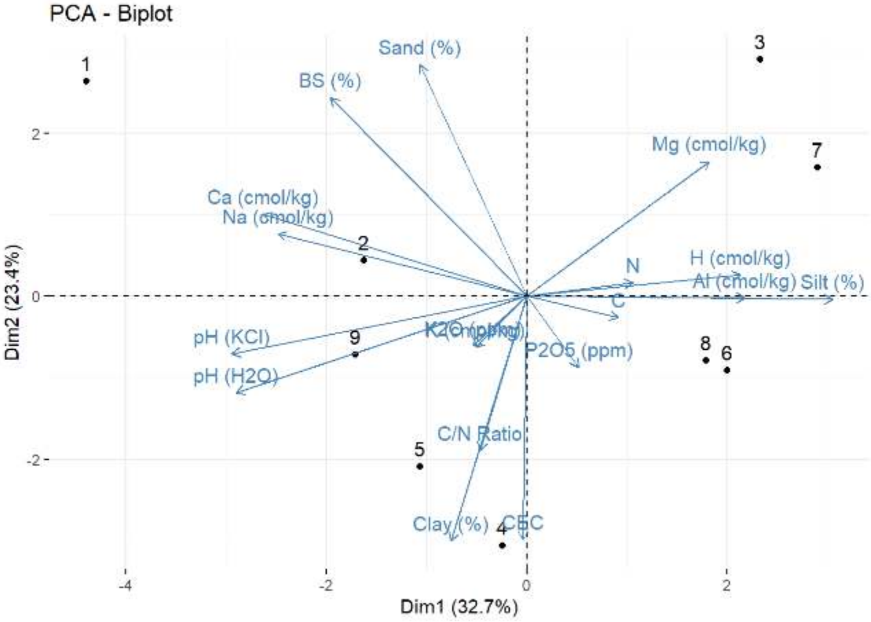

Figure 11. Biplot depth 30-60 cm.

Biplots show a strong correlation or relationship between variables and observations represented by points and vectors. The closer the point is to the vector, the closer the relationship between the observation and the variable. For example, Figure 10 and Figure 11 show that observation points 3 and 7 in Principal Component Analysis have the same characteristics and have a close correlation or relationship with the element Mg (cmol/mg) at each sample depth (0-30 cm and 30-60 cm). Based on Table 11 and Table 12, the reclamation area for both 0-30 cm and 30-60 cm depths have average values of soil chemical parameters

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

classified as very low and low, except for the base saturation parameter. As for soil physical properties, the reclaimed area has a high clay content. The condition of the reclaimed area can be categorized as having infertile land status.

Ex-mining land is generally infertile. A lack of organic matter can lead to infertile soil, low pH, high clay content, or very low nutrients (Hartati and Sudarmadji, 2016; Feng et al., 2019; Nadalia and Pulunggono, 2020). Soil conditions greatly affect plant growth and diversity (number of living and growing plants). Nutrients become available to plants but are controlled by interactions between physical, chemical, and biological properties. The availability of nutrients in the soil is very important for plant growth and diversity. Soil fertility is inseparable from the balance of physical, chemical, and biological properties. Soil fertility can be improved in various ways, including by applying various soil amendments (ameliorants) (Agus et al., 2019). Ameliorants that can be used to improve soil quality in ex-mining areas are non-organic ameliorants, organic ameliorants, and biological ameliorants (Sulakhudin et al., 2017; Purnamayani et al., 2019; Ghaida et al., 2020). The application of biofertilizers such as mycorrhiza can improve plant growth, especially on degraded land conditions such as former limestone mining land (Ghaida et al., 2020). Using mycorrhizal fungi as biofertilizers can save fertilizer costs and reduce environmental pollution due to the excessive use of synthetic fertilizers (Daras et al., 2015). The addition of compost significantly increased organic matter content, C/N ratio of macronutrients (N, P, K), and improved soil texture. The application of mycorrhizae and rhizobium significantly increased the growth of forest plants such as "trembesi" (*Samanea saman*), "jabon" (*Anthocepalus cadamba*) and "ganitri" (*Elaeocarpus angustifolus*) on former gold mine land (Setyaningsih, 2023).

To increase diversity, however, an enrichment process needs to be carried out, namely planting other plant species/revegetation (Yunanto, 2018; Amanah and Yunanto, 2019). Revegetation activities aim to restore productivity and vegetation cover in disturbed areas (ex-mining land) and improve soil quality and microclimate (Prematuri et al., 2020; Pratiwi et al., 2021).

Conclusion

The results showed that the dominant plant species planted were *P. merkusii, H. brasiliensis,* and *E. cyclocarpum*. The mean growth value of the diameter and height of these plants is below the mean value of the same species, both planted in the former mining area and not. In addition, the biodiversity value in the reclaimed area is very low. The low growth of diameter, height, and biodiversity conditions in the reclamation area may be due to the infertile soil conditions. The mean values of soil physical and chemical properties at two depths in the reclamation area show low values like pH, organic C, CEC, etc. There are "puspa" (*Schima wallichii*) species growing naturally in the reclamation area, indicating that the reclamation activities have created a good environment for other tree species to grow naturally in the reclamation area. To increase diversity, an enrichment process should be carried out, namely planting other plant species.

Acknowledgments

The authors would like to thank the Ministry of Energy and Mineral Resources, Republic of Indonesia for funding this research. In addition, the authors would also like to thank one of the Mining Business Licences in Indonesia for allowing the author to carry out research activities in the ex-mining reclamation area.

References

Agus, C., Primananda, E., Faridah, E., Wulandari, D. and Lestari, T. 2019. Role of arbuscular mycorrhizal fungi and *Pongamia pinnata* for revegetation of tropical open-pit coal mining soils. *International Journal of Environmental Science and Technology* 7:3365-3374, doi:10.1007/s13762-018-1983-5.

Albasri, A., Tuheteru, F.D., Husna, H., Budiharta, S., Tuheteru, E.J., Mulyono, S., Yunanto, T. and Karlin, V. 2023. Composition, structure and diversity of vegetation on asphalt post-mining sites in Buton Island, Indonesia. *Floresta e Ambiente* 30(3), doi:10.1590/2179-8087-FLORAM-2023-0022.

Amanah. F. and Yunanto, T. 2019. Mine reclamation period to successfully meet criteria in Indonesia. In: Fourie, A.B. and Tibbett, M. (eds), *Mine Closure 2019; Proceedings of the 13th International Conference on Mine Closure. Australian Centre for Geomechanics, Perth*, doi:10.36487/ACG_rep/1915_103_Amanah.

Cain, S.A. 1938. The species-area curve. The American Midland Naturalist, 573-581.

Christian, Y., Afandi, A., Prabowo, B., Rikardi, N. and Desmiwati. 2023. The feasibility of converting ex-coal mining void into aquaculture in North Kalimantan. *Journal of Degraded and Mining Lands Management* 10(2):4143-4153, doi:10.15243/jdmlm.2023.102.4143.

Daras, U., Trisilawati, O. and Sobari, L. 2013. Effect of mycorrhizal and ameliorant on coffee seed growth. *Buletin RISTRI* 2:145-156 (*in Indonesian*).

de Faria, S.M., Ringelberg, J.J., Gross, E., Koenen, E.J.M., Cardoso, D., Ametsitsi, G.K.D., Akomatey, J., Maluk, M., Tak, N., Gehlot, H.S., Wright, K.M., Teaumroong, N., Songwattana, P., de Lima, H.C., Prin, Y., Zartman, C.E., Sprent, J.I., Ardley, J., Hughes, C.E. and James, E.K. 2022. The innovation of the symbiosome has enhanced the evolutionary stability of nitrogen fixation in legumes. *New Phytologist* 235(6):2365-2377, doi:10.1111/nph.18321.

Feng, Y., Wang, J., Bai, Z. and Reading, L. 2019. Effects of surface coal mining and land reclamation on soil properties: A review. *Earth-Science Reviews* 191:12-25, doi:10.1016/j.earscirev.2019.02.015.

Ghaida, S.H., Wasis, B. and Budi, S.W. 2020. Application of arbuscular mycorrhizal fungi and soil ameliorant on the growth of *Leucaena leucocephala* in limestone post-

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

mining soil media. *Jurnal Manajemen Hutan Tropika* 3:282-290, doi:10.7226/jtfm.26.3.282.

Gonçalves, F.M.P., Revermann, R., Gomes, A.L., Aidar, M.P.M., Finckh, M. and Juergens, N. 2017. Tree species diversity and composition of Miombo woodlands in South-Central Angola: A chronosequence of forest recovery after shifting cultivation. *International Journal of Forestry Research* 2017, doi:10.1155/2017/6202093.

Haigh, M., Woodruffe, P., D'Aucourt, M., Aun, E., Wilding, G., Fitzpatrick, S., Filcheva, E. and Noustorova, M. 2020. Successful ecological regeneration of opencast coal mine spoils through forestation: From cradle to grove. *Minerals* 10:1-27, doi:10.3390/min10050461.

Hartati, W. and Sudarmadji, T. 2016. Relationship between soil texture and soil organic matter content on mined-out lands in Berau, East Kalimantan, Indonesia. *Nusantara Bioscience* 8:83-88, doi:10.13057/nusbiosci/n080115.

Hayati, N., Windusari, Y. and Dahlan, Z. 2021. Types of amphibia in coal mine reclamation of PT. Bukit Asam, Tbk. Tanjung Enim, South Sumatera. *BIOVALENTIA: Biological Research Journal* 7(1):18-24, doi:10.24233/biov.7.1.2021.208.

Hytönen, J., Nurmi, J., Kaakkurivaara, N. and Kaakkurivaara, T. 2019. Rubber tree (*Hevea brasiliensis*) biomass, nutrient content, and heating values in Southern Thailand. *Forests* 10(8), doi:10.3390/f10080638.

IPB University. 2013. Mine reclamation training materials. Slide Presentation. IPB University, Bogor, Indonesia

Ishmah, S.N., Permana, M.D., Firdaus, M.L. and Eddy, D.R. 2020. Extraction of silica from Bengkulu beach sand using alkali fusion method. *PENDIPA Journal of Science Education* 4(2):1-5, doi:10.33369/pendipa.4.2.1-5.

Iskandar, I., Suryaningtyas, D.T., Baskoro, D.P.T., Budi, S.W., Gozali, I., Suryanto, A., Kirmi, H. and Dultz, S. 2022. Revegetation as a driver of chemical and physical soil property changes in a post-mining landscape of East Kalimantan: A chronosequence study. *Catena* 215, doi:10.1016/j.catena.2022.106355.

Kara, F. 2021. Comparison of tree diameter distributions in managed and unmanaged Kazdağı fir forests. *Silva Balcanic* 22(1):31-43, doi:10.3897/silvabalcanica.22.e58020.

Lamprecht, H. 1989. *Silviculture in the Tropics*: *Tropical Forest Ecosystems and Their Tree Species - Possibilities and Methods for Their Long-term Utilization*. Publisher: Deutsche Gesellschaft für Technische Zusammenarbeit, 296 pages, ISBN: 388085422X, 9783880854222.

Leila, B., Loubna, B. and Ali, B. 2020. Impacts of mining activities on soil properties: case studies from Morocco mine sites. *Soil Science Annual* 71(4):395-407.

Lestari, K.G., Budi, S.W. and Suryaningtyas, D.T. 2022. The impact of revegetation activities in various post-mining lands in Indonesia (study of literature). *IOP Conference Series: Earth and Environmental Science* 959(1), doi:10.1088/1755-1315/959/1/012038.

Lewis, S. and Rosales, J. 2020. Restoration of forested lands under bauxite mining with emphasis on Guyana during the first two decades of the XXI century: A review. *Journal of Geoscience and Environment Protection* 8:41-67, doi:10.4236/gep.2020.811003.

Mikroutsikos, A., Theocharis, A.I., Koukouzas, N.C. and Zevgolis, I.E. 2023. Slope stability of reclaimed coal mines through a new water filling index. *Journal of Rock Mechanics and Geotechnical Engineering* 16(3):828-839, doi:10.1016/j.jrmge.2023.08.022.

Mulenga, C. 2022. Soil governance and the control of mining pollution in Zambia. *Soil Security* 6:100039, doi:10.1016/j.soisec.2022.100039.

Nadalia, D. and Pulunggono, H.B. 2020. Soil characteristics of post-mining reclamation land and natural soil without top soil. *Journal of Degraded and Mining Lands Management* 7(2): 2011-2016, doi:10.15243/jdmlm.2020.072.2011.

Nugrahanto, G., Na'iem, M., Indrioko, S., Faridah, E., Widiyatno, and Abdillah, E. 2022. Genetic parameters for resin production of Pinus merkusii progeny test collected from three seed sources in Banyumas Barat Forest District, Indonesia. *Biodiversitas* 23(4):2010-2016, doi:10.13057/biodiv/d230436.

Nutayla, N., Rejo, A. and Adhiguna, R.T. 2023. Coal Post-Mining Reclamation Using Pterocarpus indicus. *Journal of Ecological Engineering* 24(12):366-376, doi:10.12911/22998993/174091.

Oktofian, W.E., Biantary, M.P., Yahya, Z., Kamarubayana, L., Tirkaamina, M.T. and Ramayana, S.A. 2023. The degree of stability of rubber stands (*Hevea brasiliensis*) in the timber estate area of PT. Sylvaduta District Kembang Janggut, Kutai Kartanegara District East Kalimantan Province. *Journal of Agriculture and Ecology Research International* 24(5):135-141, doi:10.9734/jaeri/2023/v24i5551.

Pambudi, P.A., Utomo, S.W., Soelarno, S.W. and Takarina, N.D. 2023. Coal mining reclamation as an environmental recovery effort: a review. *Journal of Degraded and Mining Lands Management* 10(4):4811-4821, doi:10.15243/jdmlm.2023.104.4811.

Patabang, M. and Hardjanto, H. 2021. Stem volume equation for constructing local volume table of *Pinus merkusii* Jungh et de Vriese in Tana Toraja community forest. *Biogenesis: Jurnal Ilmiah Biologi* 9(2):137, doi:10.24252/bio.v9i2.22281.

Patabang, M., Malamassam, D. and Hardjanto. 2014. Growth model of pine (*Pinus merkusii* Jungh. Et de Vriese) stand on community forest in Tana Toraja Regency. *Jurnal Manajemen Hutan Tropika* 20(1):1-8, doi:10.7226/jtfm.20.1.1.

Pawul, M., Kępys, W. and Śliwka, M. 2022. The role of natural succession in the reclamation of mining waste disposal facilities. *Inzynieria Mineralna* 1(2-50):159-165, doi:10.29227/IM-2022-02-21.

Pratiwi, Narendra, B.H., Siregar, C.A., Turjaman, M., Hidayat, A., Rachmat, H.H., Mulyanto, B., Suwardi, Iskandar, Maharani, R., Rayadin, Y., Prematuri, R., Turjaman, M., Sato, T. and Tawaraya, K. 2020. The impact of nickel mining on soil properties and growth of two fast-growing tropical trees species. *International Journal of Forestry Research* 2020:1-9. doi:10.1155/2020/8837590.

Prematuri, R., Turjaman, M., Sato, T. and Tawaraya, K. 2020. Post bauxite mining land soil characteristics and its effects on the growth of *Falcataria moluccana* (Miq.) Barneby & J. W. Grimes and *Albizia saman* (Jacq.) Merr. *Applied and Environmental Soil Science* 2020, Article ID 6764380, doi:10.1155/2020/6764380.

Purnamayani, R., Hendri, J. and Cahyana, D. 2019. The effect of ameliorant application in abundance of soil microbiology on coal mine reclamation land at Muaro Jambi Regency of Jambi Province. *IOP Conference Series Earth and Environmental Science* 1:012053, doi:10.1088/1755-1315/393/1/012053.

Rehman, G., Khattak, I., Hamayun, M., Rahman, A., Haseeb, M., Umar, M., Ali, S., Iftikhar, Shams, W.A. and

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International

Pervaiz, R. 2021. Impacts of mining on local fauna of wildlife in District Mardan & District Mohmand Khyber Pakhtunkhwa Pakistan. *Brazilian Journal of Biology* 84: PMID: 34932632, doi:10.1590/1519-6984.251733.

Rosikin, Prasetyo, L.B. and Hermawan, R. 2023. Assessment of the success of canopy cover revegetation of former coal mine lands with Forest Canopy Density (FCD) Model in Kutai Kartanegara, East Kalimantan. *Jurnal Pengelolaan Sumberdaya Alam dan Lingkungan*, 13(4):574-585, doi:10.29244/jpsl.13.4.574-585.

Safitri, B., Wahyudi, W. and Christopheros. 2020. Distribution of diameter of sengon plants (*Paraserianthes falcataria*) as an indicator of normal growth. *Jurnal Hutan Tropika* 15(1):43-50, doi:10.36873/jht.v15i1.1713 (*in Indonesian*).

Sakellari, C., Roumpos, C., Louloudis, G. and Vasileiou, E. 2021. A review about the sustainability of pit lakes as a rehabilitation factor after mine closure. *Materials Proceedings* 1:52, doi:10.3390/materproc2021005052.

Setyaningsih, L. 2023. Reforestation in the reclamation area of Pongkor Gold Mining. *Jurnal Sains Natural* 13:212-220, doi:10.31938/JSN.V13I4.649.

Šofranko, M., Végsöová, O., Kalász, T., Sulovec, V., Beca, J. and Šuver, M. 2020. Effect of reclamation on an environment impaired by mining activity: A case study. *Polish Journal of Environmental Studies* 29(5):3329-3337, doi:10.15244/pjoes/115097.

Sonter, L.J., Ali, S.H. and Watson, J.E.M. 2018. Mining and biodiversity: Key issues and research needs in conservation science. *Proceedings of the Royal Society B: Biological Sciences* 285(1892), doi:10.1098/rspb.2018.1926.

Staporn, D., Marod, D., Wongprom, J. and Diloksumpun, S. 2022. Drivers of native species regeneration in the process of restoring a dry evergreen forest from exotic tree plantations in Northeastern Thailand. *Forests* 2022, 13(8):1321, doi:10.3390/f13081321.

Sulakhudin, Suswati, D. and Hatta, M. 2017. The effect of ameliorants on improvement of soil fertility in post-gold mining land at West Kalimantan. *Journal of Degraded and Mining Lands Management* 4:873-880, doi:10.15243/jdmlm.2017.044.873.

Villa, P.M., Meira-Neto, J.A.A., Diniz, É.S., Ali, A., Neri, A.V., Martins, S.V., Campos, P.V., Pinto-Junior, H.V., da Costa, J.S., Coelho, A.J.P., Bao, F., de Araújo Lima, G. and Rapini, A. 2023. Soil factors rather than stand age drive tree phylogenetic diversity along Amazon Forest succession. *Ecological Engineering* 189(December 2021), doi:10.1016/j.ecoleng.2023.106915.

Wahyudi, H. and Palupi, W.A. 2022. Natural resources curse in Indonesia. *International Journal of Energy Economics and Policy* 13(2):349-356, doi:10.32479/ijeep.14077.

Waitkus, A.K. 2022. Sustainable reclamation practices for a large surface coal mine in shortgrass prairie, semiarid environment (Wyoming, USA): case study. *International Journal of Coal Science and Technology* 9(1), doi:10.1007/s40789-022-00502-3.

Widjanarko, A.P. and Gultom, Y.M.L. 2024. A changing landscape: Exploring the relationship between clean and clear status policy, coal mining, and deforestation. *Jurnal Manajemen Hutan Tropika* 30(1):94-106, doi:10.7226/jtfm.30.1.96.

Yunanto, T., Amanah, F. and Wisnu, N.P. 2021. The possibility of reclamation criteria success in Indonesia: Soil condition, vegetation structure and species composition. *Journal of Degraded and Mining Lands Management* 9(1):3201-3210, doi:10.15243/jdmlm.2021.091.3201.

Yunanto, T., Mitlohner, R. and Bürger-Arndt, R. 2019. Vegetation development and the condition of natural regeneration after coal mine reclamation in East Kalimantan, Indonesia. In: Fourie, A.B. and Tibbett, M. (eds), *Mine Closure 2019: Proceedings of the 13th International Conference on Mine Closure,* Perth, pp. 1289-1302, doi:10.36487/ACG_rep/1915_102.

Yunanto, T., Suparno, S., Amanah, F., Fajriatunnisa, F. and Wisnu, N.P. 2022. Reclamation of a limestone quarry: effect of poultry manure and humic acid on the soil improvement. *Journal of Degraded and Mining Lands Management* 9(4):3773-3785, doi:10.15243/jdmlm.2022.094.3773

Yuningsih, L., Hermansyah, Ibrahim, E. and Marsi. 2021. Diversity, structure and composition of vegetation in post-coal mining reclamation area in Sumatra, Indonesia. *Biodiversitas* 22(8):3392-3400, doi:10.13057/biodiv/d220836.

Zhao, Y., Wang, Y., Zhang, Z., Zhou, Y., Huang, H. and Chang, M. 2023. The evolution of landscape patterns and its ecological effects of open-pit mining: A case study in the Heidaigou mining area, China. *International Journal of Environmental Research and Public Health* 20(5), doi:10.3390/ijerph20054394.

Zine, H., Hakkou, R., Elmansour, A., Elgadi, S., Ouhammou, A. and Benzaazoua, M. 2023. Native plant diversity for ecological reclamation in Moroccan open-pit phosphate mines. *Biodiversity Data Journal* 11, doi:10.3897/BDJ.11.E104592.

Zöhrer, F. 1980. Forstinventur. Schriftenreihe "Pareys Studientexte" 26. Hamburg: Parey.

CC BY-NC 4.0 | Attribution-NonCommercial 4.0 International