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Spontaneously growing plants on revegetation sites of former coal mine in South Kalimantan Province, Indonesia

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Abstract. *Soendjoto MA, Riefani MK, Triwibowo D, Wahyudi F, Choirun D, Perdana YP. 2023. Spontaneously growing plants on revegetation sites of former coal mine in South Kalimantan Province, Indonesia. Biodiversitas 24: 1610-1620.* Plants that grow and develop on the revegetation sites of post-coal mining are not only plant species that are intentionally planted, but also those that grow spontaneously. The aim of the research was to inventory plant species that grow spontaneously on revegetation sites of former coal mine sites in South Kalimantan Province and to analyze their presence mechanism and maintenance practices. Vegetation sampling was conducted on the plots established along the path with the size of each plot was 2 x 2 m^2. All plants herbs (except grasses) and seedlings (shrubs, bushes, lianas and trees) within the plots were recorded and the vegetation composition was analyzed using Important Value Index as the parameter. Vegetation was monitored for 5 periods from 2018 to 2022 at the revegetation sites of two different planting years, i.e. 2016 and 2017. At Site-2016, 60 species belonging to 22 plant families were found and 71.67% of them grew spontaneously, while at Site-2017 there were 58 species belonging to 22 plant families and 70.69% of them were plants that grew spontaneously. Spontaneously growing species varied not only by location, but also by monitoring period. They are present at revegetation sites through seed dispersal mechanisms facilitated by natural activities (such as animals, wind, and water) as well as human activities. There are several management practices to facilitate vegetation succession, one of which is through spraying herbicides of weeds and invasive understorey species.

Keywords: Coal mining, monitoring, plant, revegetation, spontaneously growing

INTRODUCTION

The majority of coal mining activities in Indonesia are conducted using an open pit system. The implementation of this system requires land clearing (including cutting down vegetation and removing everything on the land surface), stripping soil layers (both topsoil and subsoil), temporarily placing the soil layers in other site, before finally extracting the coal deposits at a depth of several meters to two hundred meters below the ground surface. Having the coal deposits been extracted, the ex-mined land is then reclaimed. During the reclamation process, soil layers that have been placed temporarily on a site are returned to the mined site in accordance with their original position before mining is carried out. Such procedures are common practices in open pit mining systems across the world (López-Marcos et al. 2020).

After the soil reclamation, the ex-mined land needs to be revegetated, which is mandatory activity to be conducted by mining companies. Revegetation aims to improve the quality of the ex-mined soil related to its physical and chemical characteristics (Pratiwi et al. 2021; Yuningsih et al. 2021a), improve microclimatic conditions (Pratiwi et al. 2021), and also preserve biodiversity (Jordan et al. 2019). The revegetation of ex-mined land is usually started with planting ground cover vegetation (sometimes called cover crops) with the purpose of rapidly covering the soil surface. The presence of cover crops is expected to reduce run-off caused by rainwater and minimize soil erosion, especially when heavy and long rainfall occurs (Mohamadi and Kavian 2015; Ngezahayo et al. 2019; Piacentini et al. 2018; Zhao et al. 2019).

Plants that are widely known to be used as cover crops are legumes or plant species from Fabaceae family (Kocira et al. 2020), including *Calopogonium mucunoides*, *Centrocema pubescens*, and *Pueraria phaseoloides* (Iskandar et al. 2022; Prayogo and Ihsan 2018; Soendjoto et al. 2014). The rationale for choosing legumes as cover crops is because of their symbiosis with *Rhizobium bacteria,* which has the ability to fix atmospheric nitrogen (Westhoek et al. 2021) and increase the nitrogen content in the soil (Dane et al. 2017). Nitrogen is one of the three macronutrients needed for plant growth and development (Carranca et al. 2015; Fathi 2022; Yang et al. 2022).

Once the ex-mined site is covered by cover crops, planting of woody vegetation or tree species is carried out. The tree species planted are commonly those with a stem diameter of more than 20 cm or a height of more than 20 m. The tree species are planted to protect the soil surface from rainwater and erosion, help increase or accelerate soil fertility, regain forest cover and increase biodiversity (Guo et al. 2018; Mensah 2015; Navarro-Ramos et al. 2022). Another aim of the planting of pioneer trees is to create a microclimate that makes the revegetation site suitable for the growth and development of other plants, both the same and different species. Improved environmental conditions will allow manual planting, which usually uses woody plants.

Planting woody plants begins with making planting holes that are at least 30 cm long, 30 cm wide and 30 cm deep. After the manure is sprinkled in the hole, a few days or weeks later, the seedlings of plant species from the nursery are planted and cared for. The woody plants that are deliberately planted are not only legumes, such as *Acacia auriculiformis*, *Acacia mangium*, *Cassia siamea*, *Paraserianthes falcataria*, and *Samanea saman* (Mulyadi et al. 2022; Soendjoto et al. 2014; Yuningsih et al. 2021b), but also non-legumes. Several non-legume plants are categorized as pioneer species and/or local species, such as *Gmelina arborea*, *Hibiscus tiliaceus*, *Neolamarckia cadamba*, *Peronema canescens*, *Syzygium polyanthum*, and *Vitex pinnata* (Adman et al. 2020; Isdianti et al. 2022; Soendjoto et al. 2014).

In its development, there are other plants that are also present in the revegetation site. These spontaneously growing species are no less important. They can grow and develop together with the species that are deliberately planted. These two plant groups form a new ecosystem which in turn can be an indicator of the success of revegetation on ex-mining land. The aims of the study were to inventory plant species that grow spontaneously or not through intentional planting on revegetation sites of a former coal mine site in South Kalimantan and to analyze their presence and maintenance. There were three questions to answer in this research: (i) What species can be classified as spontaneously growing plants? (ii) How can they grow on the revegetation site? (iii) What treatments need to be applied by coal mining companies in the management of spontaneously growing plants to accelerate vegetation recovery?

MATERIALS AND METHODS

Study area and period

The research was carried out at two former coal mine sites that had been reclaimed and then revegetated. These sites are administratively located in two districts in South Kalimantan Province, Indonesia (Table 1, Figure 1). The first site was located in Balangan District and planting occurred in 2016, while the second site was located in Tabalong District and planting occurred in 2017. These sites are under the operational area of the coal mining company PT Adaro Indonesia and have been determined by the company to be monitored in five monitoring periods from December 2018 to May 2022.

Table 1. Plant monitoring sites in the revegetation areas of PT Adaro Indonesia, South Kalimantan Province, Indonesia

No.	Name and coordinates of monitoring site			Year and area of revegetation sites (ha)		Plant age in the monitoring period I
1	PRG-HW2	2°18'19.52"S	115°28'51.17"E	Quarter I - 2016	16.46	2 years 9 months
2	TTP-LW5	2°10'56.37"S	115°31'20.13"E	Quarter II - 2017	54.84	1 years 5 months

Notes: The monitoring period was started in December 2018 and there were five monitoring periods between 2018 and 2022. For calculating age, March 1st was considered for Quarter I (January-April) and July 1st for Quarter II (May-August)

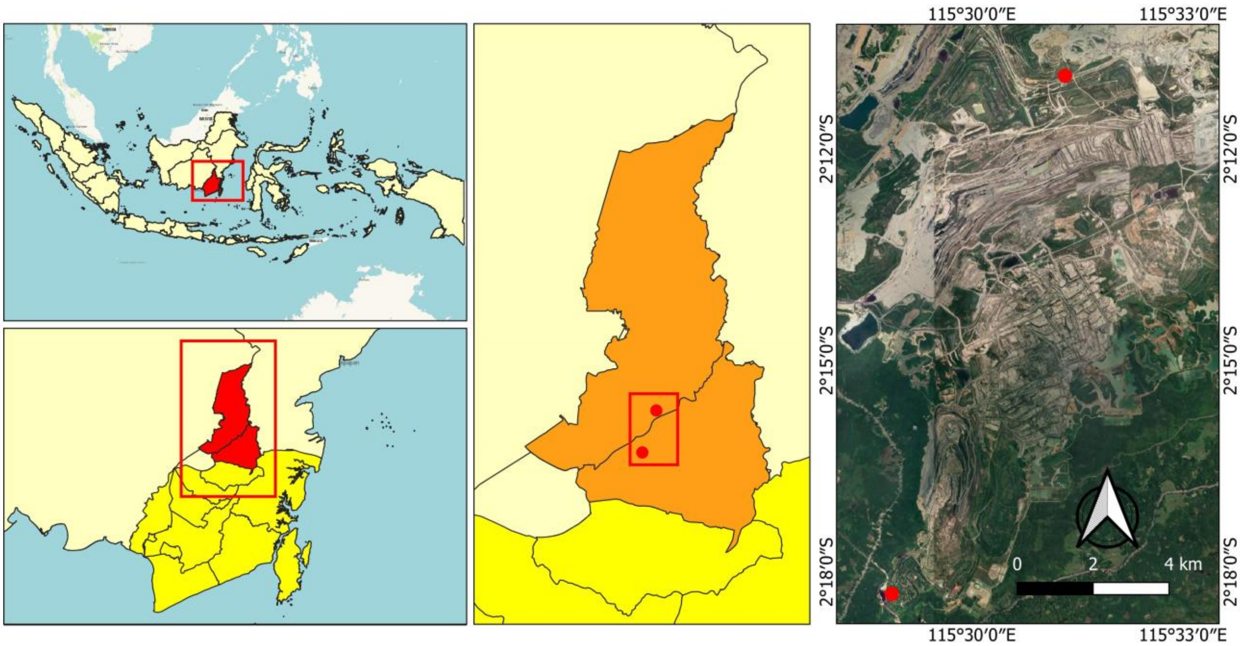

Figure 1. Map of the study area in Tabalong and Balangan Districts, South Kalimantan Province, Indonesia

Apart from the area and year of planting, there were some differences between Site-2016 and Site-2017. The sampled location of Site-2016 was placed in the center of the revegetation site or not directly adjacent to open areas. This location is relatively flat with a slope of almost 0 degrees, making the chances of erosion small. Until the last monitoring period conducted in May 2022, the sampled area of Site-2016 had a relatively dense vegetation cover with many trees with a height of more than 10 m. At a distance of about 100 m to the south of the sampled area, there was an open area in the form of a coal stockpile. This one-hectare area was located approximately at Kilometer 72 next to the PT Balangan Coal hauling road which connects the company's coal mining site to the loading port in Kelanis, South Barito District, Central Kalimantan.

Site-2017 was located slightly northeast of Site-2016 at a distance of approximately 14.5 km. The sampled location was also placed in the center of the revegetation sites, but this site tended to be surrounded by open areas. The shortest distance between the sampled location and the open area to the north was about 15 m. The shortest distance to the south, which consisted of flat land and little vegetation was about 10 m, the inspection road was about 30 m, the area with slightly sloping topography was about 50 m, and the water drainage from the mine to the settling pond was about 150 m. The trees that grew in the two open areas were few and scattered, with a height of only about 8-10 m. Site-2017 had a slope of 20 degrees with a width of 30 m. The presence of plant species in the revegetation sites was due to planting to accelerate vegetation recovery on the reclamation site, which was completely without vegetation. Due to the relatively large area of the reclamation site, the mining company revegetated the area through hydroseeding, a method of seeding by spraying a mixture of water and various seeds of cover crops, mainly from the Fabaceae family, with the help of machines. Hydroseeding is a method of revegetating land by spraying a mixture of various plant seeds and mulch (Anshari et al. 2018). The method has been applied to former coal mines in northern Spain (González-Alday et al. 2008; Sigcha et al. 2018) and has an impact on floristic composition (Martínez-Ruiz et al. 2007).

Data collection

The data collected was the results of plant monitoring at both Site-2016 and Site-2017 and the result of discussions with field workers regarding planting and maintenance. This monitoring was carried out with a frequency of once a year from 2018 to 2022. Plant monitoring was carried out using the plotted path method. Ten plots with a size of each plot 2x2 m^2 and a distance between plots of 20 m were permanently placed during the period of 2018-2022) in one path. In each plot, the name of the plant species was recorded and the number of individuals was counted. The plant groups considered in this study were plants that grow close to the soil surface or on the vegetation floor, including herbs (except for grasses) and seedlings of woody plants (shrubs, bushes, lianas and trees). Seedling is defined as woody plants with a height of less than 1.5 m, which represents the initial stage of the four growth stages of a woody plant or the growth stage before it reaches sapling, pole and tree.

Data analysis

Data on all plant species, along with the important value index for each type were tabulated. The data were then calculated to see the vegetation composition of species based on the parameters of Important Value Index (IVI), Frequency Relative, Density Relative using the formula 1-5 according to the site and monitoring period as shown below.

$$Fi = \frac{\text{number of sample plots where species-i found}}{\text{total sample plots}}$$

$$RFi = \frac{\text{frequency for species} - \text{i}}{\text{total frequency for all species}} \times 100\%$$

$$Di = \frac{\text{number of individuals species} - \text{i}}{\text{area of all sample plots}}$$

$$RDi = \frac{\text{density for species} - \text{i}}{\text{total density for all species}} \times 100\%$$

$$IVIi = RFi + RDi$$

Where: IVI_i = important value index for species-i, F_i = frequency of species-i, RF_i = relative frequency for species-i, D_i = density of species-i, and RD_i = relative density for species-i.

The ratio of plant species planted intentionally or the ratio of spontaneously growing plant species is calculated by the formula:

$$x = \frac{n}{N} \times 100\%$$

Where: n = the number of plant species planted intentionally or the number of plant species growing spontaneously; N = the number of all plant species in the sample path in the revegetation site.

The presence of spontaneously growing species was analyzed qualitatively based on their dispersal mechanism. The treatment given to plants in the revegetation site was analyzed based on company practices and experience. The results were then compared with existing literature.

RESULTS AND DISCUSSION

Species variation by site

A total of 78 plant species belonging to 25 families were found in the two revegetated mine sites. The total number of species as well as the number of species by origin at Site-2016 compared to those at Site-2017 was relatively the same (Table 2). From the quantitative aspect, this finding is in line with the findings of Hapsari et al. (2020) which showed that the number of plant species was slightly higher in old revegetation sites compared to young revegetation sites. However, from the aspect of quality, the species included in the quantities mentioned above were different (Table 3). *Ipomoea fistulosa*, for example, was present at Site-2016, but was absent at Site-2017. In contrast, *Dianella ensifolia* was not present at Site-2016, but was found at Site-2017. This shows that the distribution of species varied based on where they grow.

Table 2. Number of plant species in the revegetated post-mined sites during the whole monitoring period

Description	All sites	Site-2016	Site-2017
Number of all plant species	78	60	58
Number of plant species that are planted intentionally	23 (29.49%)	17 (28.33%)	17 (29.31%)
Number of plant species that grow spontaneously	55 (70.51%)	43 (71.67%)	41 (70.69%)

Note: Numbers in parentheses indicate the ratio of species planted intentionally or spontaneously growing

The number of plant species growing spontaneously is higher (about 2.5 times) compared to the number of plant species planted intentionally, both at Site-2016 and Site-2017. This result implies that plants that are planted intentionally are indeed needed to facilitate the growth of spontaneously growing species. In addition, the planted plants promote the growth of spontaneously growing species, although how quickly this occurs after planting remains unclear. Yang et al. (2022) reported that many plants grow spontaneously in wetlands after more than 20 years of natural succession and most are even native plants.

There is a rational rationale for this to explain the difference in vegetation between Site-2016 and Site-2007. Site-2016 was different from Site-2017 regarding the surrounding environmental conditions and the slope of the sample path. Site-2017 was surrounded by open areas with a shorter distance, so the conditions were relatively hotter than Site-2016. Erosion was more severe at Site-2017 than at Site-2016. This was indicated by the formation of grooves 10-15 cm wide where water flows on the ground surface. Erosion moves nutrients more easily and more quickly from the sampling route to lower topographical landscapes, where plants need the most nutrients. Erosion reduces soil nutrient content and makes soil infertile (Bashagaluke et al. 2018; Kurothe et al. 2014). Nonetheless, a more detailed analysis regarding the physical and chemical properties of the soil is needed to explain the difference between Site-2016 and Site-2007.

Species variation by monitoring period

The number of plant species varied not only by site, but also by monitoring period (Table 3). Site-2016 had 23-28 plant species, 65.22-78.26% of which grew spontaneously, while Site-2017 had 19-30 species and 63.16-77.27% of which grew spontaneously. Variations in the number of species between monitoring periods indicate fluctuations in species in the revegetation site from year to year.

Some species were found in all monitoring periods while other species were only found in certain monitoring periods. *Asystasia gangetica*, *Passiflora foetida*, *Chromolaena odorata,* and *Phyllanthus urinaria,* are examples of spontaneously growing species found in all monitoring periods. The first two species can be used to describe environmental conditions, although more in-depth research still needs to be done. The IVI of *A. gangetica* which increased from the initial monitoring period to the last period illustrates the adaptability of this species to the environment. In fact, species from the Acanthaceae family dominated the area, especially at Site-2016. *Passiflora foetida*'s IVI tended to decrease at the Site-2016, but tended to increase at Site-2017. The IVI value did indicate the actual field conditions that Site-2016 was shadier than Site-2017. *Passiflora foetida* is classified as an invasive species in several countries, such as India (Raju and Raju 2022), Australia (Jucker et al. 2020; Webber et al. 2014), and also Indonesia (Setyawati et al. 2015) which is capable of growing in harsh environment (Raju and Raju 2022). Other species, such as *Mikania micrantha, Centrosema pubescens*, and *P. phaseoloides* might not be used to indicate environmental conditions because their IVI tended to fluctuate.

Ageratum conyzoides, Porophyllum ruderale, Rhodomyrtus tomentosa, and *Vernonia cinerea* were some of the species found only in certain periods. They were all present at Site-2016, but the *A. conyzoides* was recorded only in December 2021, while the other three species were only present in November 2019. The absence of a species does not necessarily imply that it was not present at Site-2016. This absence may be due to the individuals were not found in the sampling line. The absence of the species might indicate that they are not capable of adapting with environmental changes. The environment changed slightly to become hotter, more humid, wet or inundated with water, or even shadier. In addition, such species might not compete with other for resources, both nutrients, light and space. Finally, species died as a result of intentional treatments, such as being eradicated and sprayed with herbicides.

Mechanism of species present in the post-mined revegetation site

Besides planting deliberately carried out by the company, plant species might also spontaneously recolonize or naturally grow. The mechanism of its presence can be explained as follow. Firstly, spontaneous plants are present because of the presence of mother plants growing outside or directly adjacent to the revegetation site. Many mother plants have vertical or upward stems, such as *A. conyzoides* (Figure 2), *Eclipta prostata, Lantana camara, Homalanthus populneus, Macaranga trichocarpa*, and *Vitex pubescens*. However, there are also species that grow horizontally with the stems creeping and trailing along the ground in all directions, like most *Ipomoea* and *Cucumis*. In addition, the stem climbs up the trunk of the host plant, as in *Merremia*. The ripe fruits of these plants fall directly to the soil surface and the seeds spread under the mother plant or in the surrounding area including in the revegetation site. Another possibility is that the ripe fruit opens while the stem is still attached to the mother plant. Seeds, as the forerunners of young plants or seedlings, are scattered on the ground due to gravity or shot away from the main plant because of the thrust when the fruit opens.

Table 3. List of plant species and their Important Value Index at two post-mined revegetation sites in South Kalimantan, Indonesia at five monitoring periods

Family	Spesies	Indonesian/local name	Site (planting year) 2016					Site (planting year) 2017				
			2018-12	2019-11	2020-09	2021-12	2022-05	2018-12	2019-11	2020-09	2021-12	2022-05
Herbs												
Acanthaceae	*Asystasia gangetica*	Ara sungsang	14.99	15.20	82.20	72.44	79.25	9.76	82.39	92.43	70.14	66.90
Asteraceae	*Ageratum conyzoides*	Bandotan	-	-	-	12.10	-	1.69	-	-	18.15	2.52
Asteraceae	*Blumea lacera*	Sembung kuwuk	-	-	-	-	-	2.02	-	7.74	-	-
Asteraceae	*Chromolaena odorata*	Kirinyuh	6.39	13.84	8.24	7.86	21.35	8.43	8.93	19.40	11.55	26.79
Asteraceae	*Clibadium surinamense*	Jepangan	-	-	-	-	-	1.69	-	-	15.35	11.59
Asteraceae	*Eclipta prostata*	Urang aring	3.01	-	-	3.03	-	1.69	-	-	-	-
Asteraceae	*Melanthera biflora*	Seruni laut	-	-	-	-	-	2.02	-	-	-	2.52
Asteraceae	*Mikania micrantha*	Sambung rambat	14.28	-	20.13	14.87	14.13	2.02	28.21	4.84	7.44	7.56
Asteraceae	*Porophyllum ruderale*	Ketumbar bolivia	-	10.57	-	-	-	24.23	2.52	2.42	-	-
Asteraceae	*Vernonia cinerea*	Sawi langit	-	4.74	-	-	-	-	-	-	2.06	5.85
Cleomaceae	*Cleoma rutidosperma*	Maman lanang	-	-	-	-	-	2.02	-	2.42	-	-
Convolvulaceae	*Ipomoea fistulosa*	Kangkung pagar	-	-	-	-	1.84	-	-	-	-	-
Convolvulaceae	*Ipomoea obscura*	Bunga bintang-putih	-	-	-	2.26	1.98	-	-	-	1.74	-
Convolvulaceae	*Ipomoea triloba*	Bunga bintang-ungu	-	5.28	-	-	-	6.74	-	-	-	-
Convolvulaceae	*Merremia peltata*	Mantangan	18.41	-	7.12	8.42	8.34	-	8.32	2.42	-	-
Convolvulaceae	*Merremia umbellata*	Akar slemang	10.88	2.23	-	-	2.26	-	9.79	-	-	-
Costaceae	*Costus speciosus*	Pacing	-	-	-	-	6.50	-	-	-	-	-
Cucurbitaceae	*Coccinia grandis*	Papasan	-	-	2.52	3.77	-	-	2.37	2.42	-	-
Cucurbitaceae	*Cucumis maderaspatanus*	Timun india	-	-	-	1.73	-	-	-	-	0.94	-
Euphorbiaceae	*Claoxylon indicum*	Talingkup	-	-	-	-	-	2.02	-	-	1.59	-
Euphorbiaceae	*Manihot esculenta*	Singkong	-	-	-	-	-	1.69	-	-	-	-
Fabaceae	*Calopogonium mucunoides*	Kacang asu	-	-	-	-	-	-	-	-	-	5.30
Fabaceae	*Centrosema plumieri*	Kacang hantu	-	-	21.19	-	-	-	-	-	-	-
Fabaceae	*Centrosema pubescens*	Sentro	49.82	26.70	-	16.04	16.96	29.28	7.87	19.89	2.06	-
Fabaceae	*Crotalaria pallida*	Kekecrekan	-	-	-	-	-	1.69	-	-	-	-
Fabaceae	*Crotalaria retusa*	Orok-orok	-	-	2.97	-	-	2.36	-	-	-	-
Fabaceae	*Desmodium heterocarpon*	Buntut meyong	-	2.23	-	-	-	9.78	-	-	-	-
Fabaceae	*Flemingia macrophylla*	Pacar kuning	-	36.45	3.20	-	-	-	22.97	-	-	-
Fabaceae	*Mimosa pigra*	Kikerbau	19.09	-	-	-	-	9.76	6.70	-	-	-
Fabaceae	*Mimosa pudica*	Putri malu	-	6.37	10.20	-	2.83	11.12	-	3.15	5.23	2.01
Fabaceae	*Pueraria javanica*	Kacang peje	3.01	13.51	-	-	-	16.14	-	-	-	-
Fabaceae	*Pueraria montana*	Garut asia timur	-	-	-	-	-	-	3.28	-	-	-
Fabaceae	*Pueraria phaseoloides*	Kacang ruji	9.79	6.10	2.63	9.06	-	22.21	2.82	8.72	5.70	-
Fabaceae	*Senna alata*	Gulinggang	3.38	3.60	-	1.51	-	-	-	-	-	-
Fabaceae	*Senna obtusifolia*	Kacang jawa	-	-	-	1.94	-	-	-	-	2.21	-
Fabaceae	*Sesbania sesban*	Jayanti	2.26	2.23	-	-	-	-	-	-	-	-
Fabaceae	*Stylosanthes scabra*	Stilo	-	5.01	-	-	-	21.21	-	2.42	-	-
Fabaceae	*Tephrosia noctiflora*	Petai balong	-	-	-	-	-	-	-	-	-	2.27
Hemerocallidaceae	*Dianella ensifolia*	Menuntil	-	-	-	-	-	-	-	-	1.59	-
Malvaceae	*Hibiscus mutabilis*	Waru landak	-	-	-	7.22	1.98	-	-	-	-	2.01
Malvaceae	*Sida rhombifolia*	Sidaguri	3.38	2.78	-	-	-	-	-	-	-	-
Malvaceae	*Urena lobata*	Pulutan	-	-	-	-	-	-	-	2.42	-	-
Melastomaceae	*Clidemia hirta*	Harendong	-	-	-	-	9.33	-	-		1.59	-
Melastomaceae	*Melastoma malabathricum*	Senduduk	-	-	-	-		1.69	-	5.08	4.27	-

Myrtaceae	*Rhodomyrtus tomentosa*	Karamunting	-	3.32	-	-	1.98	-	-	-	-	16.41
Onagraceae	*Ludwigia adscendens*	Krangkong	-	-	-	-	4.95	-	-	-	-	-
Onagraceae	*Ludwigia leptocarpa*	Pacar banyu	2.63	-	3.08	3.85	2.40	-	-	-	-	-
Passifloraceae	*Passiflora foetida*	Permot	23.68	13.89	11.78	2.04	2.40	5.05	8.78	5.81	9.65	18.67
Phyllanthaceae	*Breynia coronata*	Teturu	-	-	4.15	4.51	-	-	-	2.91	1.74	9.83
Phyllanthaceae	*Phyllanthus urinaria*	Meniran	2.63	7.19	8.58	12.16	4.81	3.70	2.67	3.64	12.81	10.41
Piperaceae	*Peperomia pellucida*	Sirih cina	-	-	9.37	-	-	-	-	-	-	-
Piperaceae	*Piper aduncum*	Sirih hutan	-	-	-	-	-	-	-	-	7.60	-
Polygalaceae	*Polygala paniculata*	Akar wangi	4.50	-	-	-	-	-	-	-	-	2.52
Rubiaceae	*Borreria alata*	Goletrak	-	-	-	-	-	-	-	11.87	13.42	6.83
Rubiaceae	*Mitracarpus hirtus*	Daun samak	-	14.28	-	-	-	-	-	-	-	-
Solanaceae	*Capsicum frutescens*	Cabe rawit	-	-	-	2.07	-	-	-	-	-	-
Solanaceae	*Solanum torvum*	Terong pipit	2.63	2.23	2.63	4.51	14.74	-	2.37	-	1.59	-
Verbenaceae	*Lantana camara*	Tembelekan	5.25	2.23	-	8.60	1.98	-	-	-	1.59	-
	Total IVI for all herb species (%)		200	200	200	200	200	200	200	200	200	200
	Total herb species (including those grown intentionally)		19	22	16	21	19	25	15	18	23	17
	Total herb species growing spontaneously		15	18	13	19	18	20	12	16	21	16
Woody plants (seedlings)												
Apocynaceae	*Alstonia scholaris*	Pulai	-	-	-	-	-	-	-	-	15.34	15.34
Combretaceae	*Terminalia catappa*	Ketapang	-	-	-	-	-	-	-	-	15.34	15.34
Euphorbiaceae	*Homalanthus populneus*	Ipo	-	-	13.85	-	-	-	-	-	-	-
Euphorbiaceae	*Macaranga trichocarpa*	Mahang	-	-	13.85	-	-	-	-	-	-	-
Fabaceae	*Acacia mangium*	Mangium	-	-	-	-	13.39	-	-	-	-	-
Fabaceae	*Cassia siamea*	Johar	69.70	-	-	-	13.39	90.00	100.00	42.22	-	-
Fabaceae	*Gliricidia sepium*	Gamal	-	-	13.85	28.72	26.79	-	-	-	-	-
Fabaceae	*Leucaena glauca*	Lamtoro	53.03	-	-	28.72	26.79	32.50	-	-	-	-
Fabaceae	*Paraserianthes falcataria*	Sengon	-	116.67	111.69	49.74	46.43	-	32.50	64.44	43.18	43.18
Fabaceae	*Pongamia pinnata*	Malapari	-	27.78	-	14.36	-	-	16.25	-	-	-
Fabaceae	*Samanea saman*	Trembesi	-	-	-	-	-	77.50	-	-	15.34	15.34
Fabaceae	*Sesbania grandiflora*	Turi	51.52	27.78	-	-	-	-	51.25	-	-	-
Lamiaceae	*Vitex pubescens*	Alaban	-	-	18.61	-	-	-	-	62.22	80.11	80.11
Melastomaceae	*Dissochaeta divaricata*	Sumiah	-	-	14.29	-	-	-	-	-	-	-
Meliaceae	*Swietenia macrophylla*	Mahoni	-	27.78	-	28.72	26.79	-	-	-	15.34	15.34
Moraceae	*Ficus benjamina*	Beringin	-	-	-	21.03	19.64	-	-	-	-	-
Myrtaceae	*Syzygium acuminatassium*	Pitaruk	-	-	-	28.72	-	-	-	-	-	-
Myrtaceae	*Syzygium lineata*	Pucuk merah	-	-		-	13.39	-	-	-	-	-
Myrtaceae	*Syzygium polianthum*	Salam	-	-	13.85	-	13.39	-	-	-	-	-
Verbenaceae	*Peronema canescens*	Sungkai	25.76	-	-	-	-	-	-	31.11	15.34	15.34
	Total IVI for all seedling species (%)		200	200	200	200	200	200	200	200	200	200
	Total seedling species (including those grown intentionally)		4	4	7	7	9	3	4	4	7	7
	Total seedling species growing spontaneously		0	0	5	1	1	0	0	1	1	1
	Total plant species per monitoring period		23	26	23	28	28	28	19	22	30	24
	Number of plant species intentionally planted per monitoring period		8	8	5	8	9	8	7	5	8	7
	Number of spontaneously growing plant species per monitoring period		15	18	18	20	19	20	12	17	22	17
	Ratio of plants planted intentionally (%) per monitoring period		34.78	30.77	21.74	28.57	32.14	28.57	36.84	22.73	26.67	29.17
	Ratio of spontaneously growing plants (%) per monitoring period		65.22	69.23	78.26	71.43	67.86	71.43	63.16	77.27	73.33	70.83

Note: The second line at the head of the table shows the monitoring year and month. For example, 2018-12 shows the monitoring period was conducted on December 2018. The cells covered in gray indicate the plant species that were planted intentionally

Figure 2. Both *Ageratum conyzoides,* whose stems stand upright (A) and *Merremia peltata,* which propagates above the ground or even climbs the trunk of a host tree (B) can act as mother plants

Secondly, the fruit or seeds are scattered and grow in the revegetation site because they are transported by animals that were previously active on mother plants in other areas. The seedlings of *Melastoma malabathricum, R. tomentosa, Solanum torvum,* or *Capsicum frutescens* are some of the plants that grew spontaneously at Site-2016 or Site-2017. The fruit or seeds were scattered at the site by frugivorous birds, such as *Pycnonotus aurigaster* (Sooty-headed Bulbul) and *Pycnonotus goiavier* (Yellow-vented Bulbul) through feces or *Dicaeum trochileum* (Scarlet-Headed Flowerpecker) and *Diaceum trigonostigma* (Orange-Bellied Flowerpecker) through vomit. These four species are a few of the birds that are present in PT Adaro Indonesia's reclamation area (Soendjoto et al. 2018). The seeds of *Clidemia hirta* were dispersed through the feces of the frugivores *Dicaeum trigonostigma* and *P. aurigaster*, while *L. camara* by *P. goiavier* (Partasasmita 2015). The seeds of various plant species are scattered after the fruit is eaten by birds (Abdussalam et al. 2021; Putra et al. 2021; Riefani and Soendjoto 2021; Romansah et al. 2018; Wulansari et al. 2020). The reduced abundance of *C. frutescens* together with the absence of forest birds on Guam demonstrates the important role birds play in the ecosystem (Egerer et al. 2018). Fruit pigeons, other large frugivores, and large fruit bats are key players in long-distance seed dispersal in fragmented landscapes (Corlett 2009).

Dispersal of fruit or seeds is also carried out by rodents and arboreal mammals. In observations at other revegetation sites of this company, we found *P. foetida* fruit being eaten by *Nasalis larvatus* (proboscis monkey), but where the seeds are scattered still needs further investigation. In testing the seeds of four plant species, Blackham and Corlett (2015) found that more seeds were transplanted in the tropical peatland forest of Central Kalimantan, Indonesia than in the non-forest. The main rodentia in the forest was *Maxomys* spp., while in the non-forest was *R. tiomanicus*. The fruits of the Annonaceae family in the Bogor Botanical Gardens are eaten and the seeds are scattered not only by birds (*P. aurigaster, P. goiavier*, and *Ptilinopus guava*), but also squirrels, civets, and bats (Handayani 2022).

Thirdly, the fallen fruit and seeds are carried by the wind. The shape of the fruit or seeds of some species might facilitate the wind to transport seeds. If the environmental conditions at the revegetation site are suitable, the seeds can grow and develop into new individuals or seedlings as happened to *Porophyllum ruderale* and *Vernonia cinerea*. The seeds of these plants are small and light and wrapped or attached to organs similar to cotton hairs which are easily detached and carried by the wind. *Vernonia cinerea* which grows in open or slightly shaded areas has seeds that germinate and become new individuals during the rainy season (Rao et al. 2017).

Fourthly, the seeds may also be dispersed by water. Rainwater drops fruit or seeds from the parent plant onto the soil surface. The fruit or seeds are then transported by the flow of water and then stop at a point that is lower in topography and is a revegetation site. *Senna alata* and *Ludwigia leptocarpa* are examples of plants whose dispersal is assisted by water flows. *Senna alata* is associated with riparian areas that facilitate its dispersal (Navarro and Rodríguez-Estrella 2020). *Ludwigia leptocarpa* seeds separate from the fruit and germinate while floating in water (Oziegbe and Faluyi 2012).

Fifthly, seeds can be dispersed due to human activities. One example of human activity which might facilitate seed dispersal at mining sites is the removal of topsoil and subsoil from the site to be mined to the temporary disposal area and from the temporary disposal area to the revegetation site. The topsoil removed might consist of generative organs (fruits, seeds) and vegetative organs (stems, tubers) of a plant species and these organs might grow into new individuals. Seeds stored in soil seed banks are generated by in-situ vegetation or dispersed by ex-situ vegetation or from nearby sites (Wang et al. 2022). The density of grass and herb seeds in most vegetation types is higher than that of woody plants (Shiferaw et al. 2018). *Clidemia hirta*, *M. malabathricum*, *Piper aduncum*, and *L. camara* are several plant species whose seeds are found in seed banks on two limestone hills in Bogor, Indonesia (Putri et al. 2021). Seeds can be in a dormant state and this is an attempt to protect themselves from unsuitable environmental conditions (Anju et al. 2022). *C. odorata* has been documented to be dispersed due to the movement of vehicles and machines controlled by humans (Rusdy 2019).

Manihot esculenta (cassava) found at Site-2017 is an example of a plant species that is thought to grow and develop through vegetative organs. It is unlikely that the presence of this species is because it was planted deliberately by company workers. In addition, the plants recommended by the company to be planted on the revegetation site are woody plants and not food-producing plants, such as cassava, corn and rice. In other words, the company forbade workers to plant revegetation sites with non-recommended plants, especially food crops.

In the history of Indonesian forestry, one of the well-known species that was spread either intentionally or unintentionally by human activities was *A. mangium*. This plant species is native to Maluku and is recognized as one of the fast-growing plants (Krisnawati et al. 2011), thus being recommended by the government to be planted in logged-over areas and industrial plantation forests in Indonesia. This species has the potential for veneer raw materials or pulp and paper raw materials. In fact, this invasive plant (Jambul et al. 2020; Koutika and Richardson 2019) has entered and developed in the Pelaihari Tanah Laut Wildlife Reserve Area, South Kalimantan Province, Indonesia, through the following mechanism (Suyanto and Soendjoto 2007). Seeds stick to the surface of motorcycle tires which are used as a means of transportation by the community through the *A. mangium* industrial plantation forest. The seeds are carried by water flowing from the industrial plantation forest to the Java Sea via wildlife reserves. The growth of seeds of this species accelerated after a fire hit the galam forest in the wildlife reserve. This species grows more dominant after the forest where it lives is burned (Jambul et al. 2020).

Planting maintenance

Planting maintenance is an activity carried out to keep the targeted plants alive, get enough nutrients, and not be susceptible to disease or even die. Targeted plants are plants that are prioritized for particular objectives, such as to increase soil fertility, produce wood for industrial raw materials, prevent erosion, regulate water management, regulate the oxygen cycle, regain vegetation cover, or be the main indicator of forest formation. Because of this priority, the presence of targeted plants is important in the revegetation site and needs to be maintained.

At the beginning of revegetation, maintenance is focused on repairing or enhancing soil quality. Soil is a growing medium and nutrient source for plants (Logsdon 2017; Morgan and Connolly 2013). The soil must be kept maintained to minimize erosion, especially during the rainy season. Fertility also needs to be increased, even though the targeted plants are classified as legumes. Organic material consisting of litter and chunks of twigs and stems are spread as mulch because this material plays an important role in maintaining soil moisture around the roots and stems of plants. Moreover, organic matter affects the soil's ability to provide nitrogen (Nadalia and Pulunggono 2020) and is the main source of nutrients for plant growth (Noviyanto et al. 2017; Turner et al. 2015) after experiencing microbial decomposition (Setyawan et al. 2011). Habitat conditions with various species will make suitable habitats for other organisms (Riefani et al. 2019).

The next practice of plant maintenance is the eradication of weeds, which are generally lianas. Liana is killed by slashing the base of the stem. Liana can climb and choke the stems of the host trees so that in turn the growth of the host tree is stunted and even dies. One of the liana species that disturbs and can kill the host plant is *Merremia peltata*. This species from Convolvulaceae is known to be invasive (Kurniawati et al. 2019; Master et al. 2013). The main stem can grow at a rate of 2.88 m/month and then climbs by twisting the stem of the target plant up to the canopy at a rate of 2.85 m/month (Fadjeri et al. 2021). In some cases, liana leaves may grow to cover the crown, thereby inhibiting the intended plant from obtaining sunlight for photosynthesis.

Spraying herbicides might also be needed to maintain to eradicate the weeds that disturb the targeted plants so that it is easier for them to obtain nutrients optimally. The absence of weeds also plays a role in helping target plant seeds that fall on the soil surface to get sunlight and can then grow and develop into seedlings or young plants. However, it should be considered that spraying with herbicides can have adverse effects because it reduces biodiversity (Schütte et al. 2017; Qi et al. 2020). Therefore, spraying herbicides is a last resort which is also less preferred to effectively control weeds. To minimize negative impacts, spraying should be done in a limited area, only around the target plants and not all over the revegetation site.

Another maintenance practice is enrichment planting. Some planted plants often grow poorly or even die. This condition is caused by many factors, such as planting carried out during the dry season, damage to seedlings from the nursery, planting holes contaminated with bacteria or viruses that cause a disease, or soil contaminated with hazardous and toxic materials. The dead plants need to be replaced by new seedlings using the same or different species. Enrichment planting is not only aimed at replacing dead plants but also at increasing the number of individuals and biodiversity. In the revegetation site, some species used for enrichment planting included *S. saman*, *Alstonia scholaris*, *Ficus benjamina*, *Terminalia catappa*, and *V. pubescens*. The company has had good results in the planting of *A. scholaris* which was planted around Buper (the camping ground of PT Adaro Indonesia) during the 2013 dry season. Around 10 individuals planted were alive in 2022 and have reached sapling or even pole level.

In conclusion, about 70% of the 78 species (25 families) of plants found in the revegetation sites in this study were plants that grow spontaneously. Species composition indicated with IVI varied by site and monitoring period. Several species were recorded in all monitoring periods while some species only appeared in a particular monitoring period. The presence of plants that grow spontaneously might be explained by the availability of mother plants to produce seeds and the medium of seed dispersal, for example, facilitated by animals, physical elements (wind, water), and human activities.

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