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Diversity and composition of plants in ex-mining revegetation lands for cement raw materials in South Kalimantan, Indonesia

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Abstract. *Soendjoto MA, Sudiarta IWK, Cangara MIZ, Patria WA, Riefani MK. 2025. Diversity and composition of plants in ex-mining revegetation lands for cement raw materials in South Kalimantan, Indonesia. Biodiversitas 26: 670-680.* PT Indocement Tunggal Prakarsa Tbk carries out open-pit mining to obtain cement raw materials in Kotabaru District, South Kalimantan, Indonesia, for the Tarjun-12 Factory. The company then undertakes the challenging task of revegetating ex-mining lands. However, there are no existing records of plant species post-revegetation, which occurred 13 to 16 years ago. This research is unique in its approach, aiming to document plant species and analyze their presence after revegetation. The methodology involves placing an observation path on each ex-mining land, with each path comprising 10 observation plots (20 m x 20 m) for recording woody plants at tree level. Each observation plot includes a small plot (10 m x 10 m) for data collection at the pole level, one plot (5 m x 5 m) for sapling level and non-woody plants (herbs), and one plot (2 m x 2 m) for seedling level and non-woody plants (grasses, ferns). The data were then analyzed after obtaining the importance value index, diversity index (Shannon-Wiener), and similarity index (Sorensen). The study revealed that more than 90% of the 155 plant species (54 families) are spontaneously grown plants, and most plant communities between ex-mining lands are dissimilar. The highest diversity is in woody plants at the sapling level and also trees on ex-laterite mining land. These results represent unique baseline data for 13-16 years post-revegetation.

Keywords: Cement raw material, diversity, ex-mining, revegetation, similarity

INTRODUCTION

There are four main raw materials in cement production which are obtained through surface mining which is generally carried out using an open pit mining system. The raw materials are limestone, clay, silica sand, and laterite. Limestone is a sedimentary rock whose main material is calcium carbonate ($CaCO_3$) (Hwidi et al. 2018). In producing cement, the need for this rock reaches 80%. Clay soil is a sedimentary rock which, although it consists of many minerals with varying contents and levels of purity (Valášková 2015; Chomyen et al. 2019), the main materials are alumina oxide (Al_2O_3) and silica oxide (SiO_2) with a ratio of 1:1.5 and 1:3 (Zaliha et al. 2015). The clay required to produce cement is 10-15%. Silica sand is a natural material whose main mineral is silica oxide (SiO_2) (Mansyur et al. 2024). This sand is an additional material in cement production with a proportion of 5-7%. Laterite is a type of soil or rock type based on its compound content consisting of laterite rich in iron (42-45% Fe_2O_3, 10-12% Al_2O_3, 20-25% SiO_2) and laterite rich in alumina (30-35% Fe_2O_3, 14-16% Al_2O_3, 25-30% SiO_2) (Satpudke and Ashutkar 2016). Laterite is also an additional material whose proportion in producing cement is only 1-2%.

This open-pit mining begins with land clearing (Lestari et al. 2021; Yuliyani et al. 2021), the activities of which are cutting down vegetation, cutting down trees, and moving pieces of vegetation or plants to another place. The next activity is to peel off the topsoil or top layer of soil where the plants grow and move it to a temporary storage location. After the land is clean, the raw material deposits are taken and transported to a temporary storage area or directly to the processing plant. If the deposit is exhausted or the volume of raw materials is met, the ex-mining land is reclaimed. The top layer of soil, including topsoil, is taken back from temporary landfills and placed permanently and remains as the top layer on ex-mining land. Reclamation, one of which is called the reclamation backfill technique (Hendriyanto et al. 2023), is carried out based on scientific principles and research as an effort to improve soil and air quality, prevent erosion, improve water quality, and reduce heavy metal pollution so that land can function again as productive land (Sastradinata 2018). Reclamation is useful for reducing or eliminating negative impacts (Prasetyo 2022), resulting from removing vegetation, removing topsoil, and also taking raw materials.

Not long after being reclaimed, the former mining land was revegetated. Revegetation is planting reclaimed land with various species of fast-growing plants, forestry plants, fruit-bearing plants, or other plants recommended by the government. Revegetation can control changes in the physical and chemical properties of soil (Iskandar et al. 2022), improve the nutrient cycle, improve the hydrological cycle, increase soil carbon levels (Li et al. 2016; Hartati and Sudarmadji 2022), and also improve the biological properties of soil, the quality of animal and microorganism habitats (Lestari et al. 2022), although not comprehensive (Widjaja and Suryaningtyas 2024).

As part of the second largest cement-producing company in Indonesia (ITP 2020), PT Indocement Tunggal Prakarsa Tbk., Factory-12 Tarjun (ITP) mines the four cement raw materials as mentioned above. Coincidentally, the locations of the ex-mining lands are close to each other. They are administratively included in the Cantung Kiri Hilir Village area, Kelumpang Hulu Sub-district, Kotabaru District, South Kalimantan. The distance of this land is around 27 km from the cement-processing factory in Tarjun, Kelumpang Hilir Sub-district, Kotabaru District. While this may seem beneficial as mining is done more easily and costs less, there are negative impacts of mining. Mining will have economic, ecological, and social impacts (Worlanyo and Jiangfeng 2021; Sun et al. 2022).

As a form of responsibility towards the environment, this cement-producing company also reclamation these ex-mining lands and revegetated them (ITP 2024). Revegetation plants include *akasia daun-lebar* (*Acacia mangium*), *jabon* (*Neolamarckia cadamba*), *teak* (*Tectona grandis*), *jengkol* (*Archidendron jiringa*), *mangga* (*Mangifera indica*), *kedondong* (*Spondias dulcis*), *sengon* (*Paraserianthes falcataria*), and *trembesi* (*Samanea saman*). Some of these plants are commonly used as revegetation plants by various coal, gold, nickel, or tin mining companies in Indonesia (Soendjoto et al. 2014, et al. 2023b; Komara et al. 2016; Kissinger et al. 2019; Setyawan et al. 2019; Drakel et al. 2021; Setyaningsih 2023). However, after revegetation was carried out, the growth and development of the revegetated plants, especially those that grew spontaneously, were not recorded at all. The absence of data means that information regarding all plants on ex-mining revegetation land cannot be obtained.

This research aims to record plant species that grow and develop in ex-mining revegetation land and analyze their presence. The results of this research answer the absence of data, as mentioned above. Apart from that, the results can be used as evaluation material to periodically monitor plant growth and development (Lestari et al. 2019), increase the quantity and quality of revegetation on ex-mining land for cement raw materials, minimize negative impacts, and maximize positive impacts on the surrounding environment.

MATERIALS AND METHODS

Study area

This research was carried out on reclaimed land from ex-limestone mines, which had been revegetated in 2010, as well as reclaimed land from ex-clay mines and ex-laterite mines, both of which had been revegetated in 2007. The research was not carried out on reclaimed land from ex-silica sand mines. The first three reclamation and revegetation lands are located close together and administratively in Cantung Kiri Hilir Village, Kelumpang Hulu Sub-district, Kotabaru District, South Kalimantan, Indonesia (Figure 1). Determining these research sites is an ITP management policy.

Table 1. Coordinate of the first plot as well as the area and year of revegetation

Ex-mining land	The coordinate of the first plot	Revegetation	
		Year	Area (ha)
Limestone	3°07'04.55"S - 115°55'54.51"E	2010	8.6
Clay	3°07'54.27"S - 115°56'15.23"E	2007	6.4
Laterite	3°08'28.17"S - 115°55'43.98"E	2007	17.0

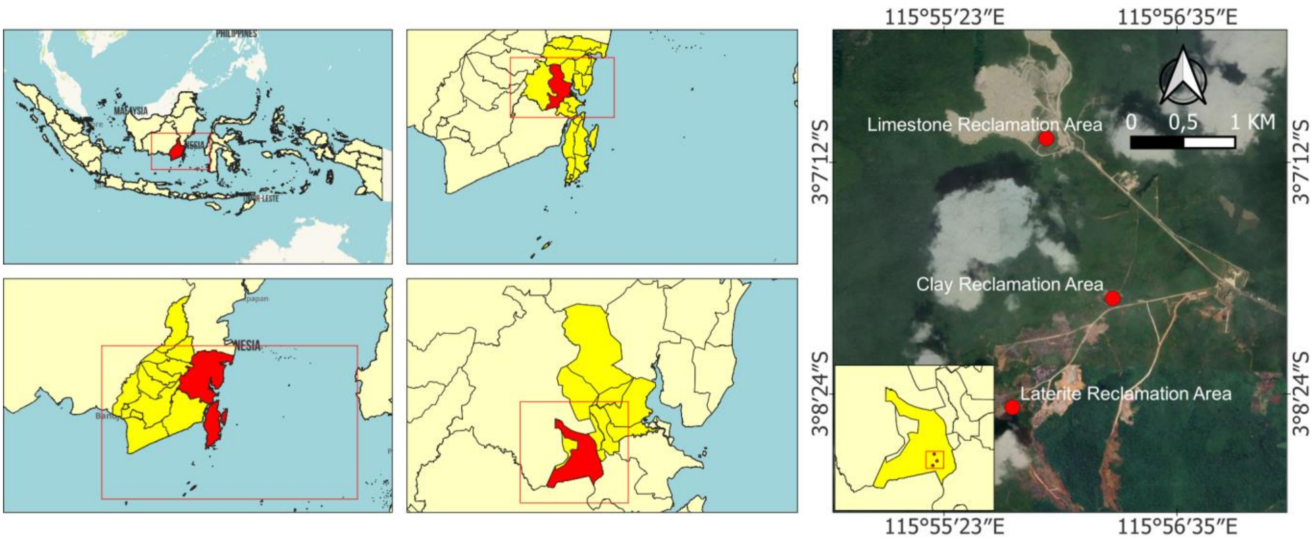


Figure 1. Location of reclamation and revegetation lands for cement raw materials mining in Cantung Kiri Hilir Village, Kelumpang Hulu Sub-district, Kotabaru District, South Kalimantan, Indonesia

Data collecting

Data was collected once during the transition of the dry and rainy seasons (September). On each ex-mining land of clay, laterite, or limestone that has been reclaimed and revegetated, one observation path is placed. This path is formed from a non-spaced row of 10 plots measuring (20 m x 20 m). In each plot, one small plot (10 m x10 m), one smaller plot (5 m x 5 m), and one smallest plot (2 m x 2 m) are placed sequentially (Figure 2).

In (20 m x 20 m) plots, woody plant species at tree level were recorded, and their diameter at breast height was measured. In (10 m x 10 m) plots, data collected is for woody plants at pole level. The diameter at breast height is also measured. Next, the (5 m x 5 m) plots were used to collect data on sapling-level woody plants and non-woody plants (herbs). Different from the two previous types of plot size, what is measured here is only the number of individuals. Finally, (2 m x 2 m) plots were used to collect data on woody plants at the seedling level as well as non-woody plants, which were included in the grass and fern groups. For these plants, only the number of individuals is counted in this plot.

The quantitative definition for the growth level of woody plants is as follows. Trees are woody plants whose trunk diameter (at breast height) is ≥20 cm. Poles are woody plants whose stem diameter (at breast height) is in the range 10≤X<20 cm. Saplings are woody plants that are ≥1.5 m high and <10 cm in diameter. Seedlings are woody plants that are <1.5 m tall.

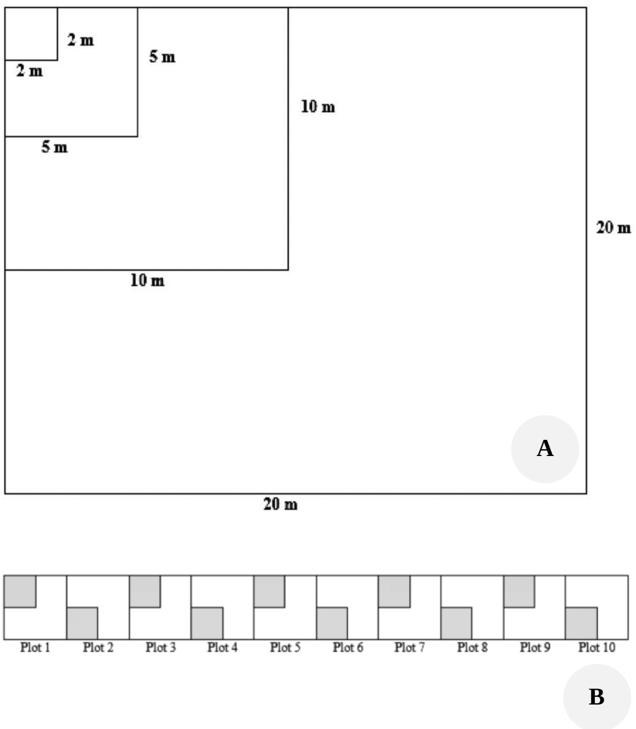


Figure 2. A. A plot (20 m x 20 m) containing three smaller plots; B. One observation path consists of a row of 10 plots (20 m x 20 m), where each plot (specifically in this figure) contains plots (10 m x 10 m) that represent smaller plots

Data analysis

The data were analyzed after an Important Value Index (IVI), a diversity index, and a similarity index were obtained. IVI for each plant species is calculated based on Formula 1-6. IVI describes the level of dominance or importance of plant species from a particular plant group or the level of growth of plant species on each ex-mining land for raw materials. Dominant species play an important role in establishing community stability (Hou et al. 2023) and structuring species distribution (Wei et al. 2020). The IVI applied to seedling and sapling woody plants as well as non-woody plants (grasses, ferns, and herbs) is calculated based on Formula 7. In comparison, the IVI for poles and tree-level woody plants is calculated based on Formula 8. The diversity index, which in this study uses the Shannon-Wiener Diversity Index (H'), is calculated based on Formula 9. The similarity index, which uses the Sorensen Similarity Index, is calculated based on Formula 10:

Formula 1

$$\text{F-i} = \frac{\text{Number of plots where species–i is found}}{\text{The sum of all plots created}}$$

Formula 2

$$\text{RF} = \frac{\text{Frequency of species–i}}{\text{The sum of the frequencies of all species}}\ x\ 100\%$$

Formula 3

$$\text{D-i} = \frac{\text{Number of individuals of species–i}}{\text{The total area of all plots}}$$

Formula 4

$$\text{RD} = \frac{\text{Density of species–i}}{\text{The sum of density of all species}}\ x\ 100\ \%$$

Formula 5

$$\text{Do-i} = \frac{\text{Total basal area of species–i}}{\text{The total area of all species}}$$

Formula 6

$$\text{RDo} = \frac{\text{Dominance of species–i}}{\text{Total dominance of all species}}\ x\ 100\%$$

Formula 7

IVI = RF + RD

Formula 8

IVI = RF + RD + RDo

Formula 9

$$\text{H'} = -\sum\left(\frac{\text{IVI–i}}{\text{IVI–as}}\right) ln \left(\frac{\text{IVI–i}}{\text{IVI–as}}\right)$$

Formula 10

$$\text{IS} = \frac{2\ \text{C}}{\text{A+B+ 2 C}}$$

In this case, F-i: frequency of species-i; RF: relative frequency; D-i: density of species-i; RD: relative density; Do-i: dominancy of species-i; RDo: relative dominancy; IVI-i: important value index of species-i; IVI-as: importance value index of all plant species; A: number of species found only in habitat A; B: number of species found only in habitat B; C: number of species found simultaneously in habitat A and B.

RESULTS AND DISCUSSION

Plant species

Overall, 155 species (54 families) of plants grew and developed in the 13-16 years between revegetation implementation and data collection (Tables 2 to 8). These plants are grouped into non-woody plants (grass, ferns, herbs) and woody plants (seedlings, saplings, poles, trees). Of all the plants found, 15 species from 9 families were intentionally planted, and the remaining 140 species (49 families) were plants that grew spontaneously.

Plants that were intentionally planted were still able to survive until this data was collected. *Centrosema pubescens* and *Pueraria javanica* is a short-lived plant that is usually used as a ground cover plant. Apart from that, there are three species of woody plants that produce fruit, namely: *Annona squamosa*, *M. indica*, and *S. dulcis*; fast-growing plants (*A. mangium*, *P. falcataria*, *S. saman*, *N. cadamba*); multipurpose plants (*Aleurites moluccana*, *A. jiringa*, *Pometia pinnata*); and wood producing plants (*Eusideroxylon zwageri*, *T. grandis*). Some species of the woody plant group even develop to the level of trees. One species that is also considered as a revegetation plant is *Elaeis guineensis*. The development of this plant is increasingly rapid because palm-oil-producing plants are planted in the form of plantation businesses by communities and oil-producing companies. The plantation location is about 1 km from the ex-mining lands.

Table 2. IVI of the grass group on limestone, clay, and laterite

Family, species	Local name	Limestone	Clay	Laterite
Cyperaceae				
Scleria bancana	*Kerisan*	-	81.80	65.28
Rhynchospora corymbosa	*Paruh emas*	21.42	-	-
Poaceae				
Axonopus compressus	*Rumput pahit*	38.46	7.94	-
Brachiaria mutica	*Rumput malela*	14.14	-	17.98
Cyrtococcum patens	*Rumput telur-ikan*	-	-	31.60
Digitaria didactyla	*Rumput jari*	-	-	36.95
Imperata cylindrica	*Alang-alang*	54.85	88.23	48.20
Panicum repens	*Rumput grinting*	-	7.34	-
Paspalum conjugatum	*Papaitan*	14.14	-	-
Pennisetum setaceum	*Ilalang merah*	56.99	8.54	-
Saccharum spontaneum	*Glagah*	-	6.14	-
	Total number of IVI (%)	200	200	200
	Maximum IVI (%)	56.99	88.23	65.28
	Number of species	6	6	5

Table 3. IVI of the fern plants on limestone, clay, and laterite

Family	Species	Local name	Limestone	Clay	Laterite
Davalliaceae	*Davallia denticulata*	*Pakis kaki-kelinci*	-	6.03	-
Gleicheniaceae	*Dicranopteris linearis*	*Paku rasam*	-	4.48	7.06
Lomariopsidaceae	*Lomariopsis lineata*	-	-	6.03	-
Lycopodiaceae	*Lycopodiella cernua*	*Paku kawat*	-	18.26	7.06
Lygodiaceae	*Lygodium circinnatum*	*Paku hata*	24.07	85.87	108.37
	Lygodium microphyllum	*Pakis panjat*	-	-	8.21
Nephrolepidaceae	*Nephrolepis bisserata*	*Paku harupat*	96.30	25.67	25.78
	Nephrolepis cordifolia	*Paku pedang*	-	-	14.12
Polypodiaceae	*Drymoglossum piloselloides*	*Paku sisik naga*	-	-	7.06
	Microgramma lycopodioides	-	-	4.48	-
	Phymatosorus scolopendria	*Pakis kutil*	-	5.25	-
Pteridaceae	*Pteris biaurita*	-	-	26.44	-
	Pteris multifida	-	-	9.13	-
	Taenitis interrupta	*Paku situnduak*	-	-	5.91
Selaginellaceae	*Selaginella* sp.	*Paku cakar-ayam*	-	8.35	9.36
Thelypteridaceae	*Christella dentata*	*Pakis lunak*	-	-	7.06
	Thelypteris unita	-	79.63	-	-
		Total number of IVI (%)	200	200	200
		Maximum IVI (%)	96.30	85.87	108.37
		Number of species	3	11	10

Table 4. IVI of herb plants on limestone, clay, and laterite

Family	Species	Local name	Limestone	Clay	Laterite
Acanthaceae	*Asystasia gangetica*	*Ara sungsang*	35.89	48.17	40.34
Apocynaceae	*Dischidia acutifolia*	*Daun korpa*	-	2.66	-
Asteraceae	*Chromolaena odorata*	*Kirinyuh*	29.19	3.64	3.25
	Clibadium surinamense	*Kiangsrat*	5.32	15.52	-
	Praxelis clematidea	*Bandotan daun-kecil*	9.92	3.64	9.46
	Vernonia cinerea	*Sawi langit*	4.92	-	-
	Wedelia biflora	*Seruni laut*	44.03	3.15	-
Convolvulaceae	*Merremia peltata*	*Bilaran tapah*	16.94	-	-
Costaceae	*Cheilocostus speciosus*	*Pacing*	-	11.62	-
	Costus spiralis	*Pacing spiral*	-	-	22.00
Dioscoreaceae	*Dioscorea pyrifolia*	*Umbi rarugadong*	-	-	3.25
Fabaceae	*Centrosema pubescens**	*Sentro*	3.71	-	-
	Mimosa pudica	*Putri malu*	22.18	6.79	8.22
	*Pueraria javanica**	*Peje*	-	5.81	-
Hypoxidaceae	*Molineria capitulata*	*Bedur*	-	-	31.46
Lamiaceae	*Hyptis capitata*	*Rumput knop*	7.82	3.15	3.87
Loranthaceae	*Macrosolen cochinchinensis*	*Benalu pentol*	-	3.64	-
Malvaceae	*Urena lobata*	*Pulutan*	-	6.30	-
Melastomaceae	*Clidemia hirta*	*Senduduk bulu*	-	2.66	-
	Melastoma malabathricum	*Senduduk*	5.73	32.07	47.91
Orchidaceae	*Dendrobium crumenatum*	*Anggrek merpati*	-	-	3.25
	Geodorum densiflorum	*Anggrek tanah*	-	2.66	-
Passifloraceae	*Passiflora foetida*	*Permot*	-	-	3.87
Polygalaceae	*Polygala paniculata*	*Akar wangi*	14.35	4.61	7.75
Smilacaceae	*Smilax aspera*	-	-	3.15	-
	Smilax gigantea	*Smilax daun-lebar*	-	5.81	-
	Smilax leucophylla	*Ubi danau*	-	6.30	-
Zingiberaceae	*Hornstedtia scyphifera*	*Patiti*	-	28.65	15.35
		Total number of IVI (%)	200	200	200
		Maximum IVI (%)	44.03	48.17	47.91
		Number of species	12	20	13

Note: *) the names of plants planted intentionally or revegetated plants

Table 5. IVI of woody plants at seedling level on limestone, clay, and laterite

Family	Species	Local name	Limestone	Clay	Laterite
Annonaceae	*Annona squamosa**	*Sarikaya*	30.95	19.62	-
Arecaceae	*Elaeis guineensis**	*Sawit*	-	19.62	-
Calophyllaceae	*Calophyllum soulattri*	*Bintangur*	-	-	97.12
Euphorbiaceae	*Macaranga gigantea*	*Merkubung*	-	-	24.59
	Macaranga hypoleuca	*Mahang bercak*	-	-	21.85
	Macaranga tanarius	*Sapat*	-	28.71	-
	Macaranga trichocarpa	*Sapat kecil*	-	19.62	-
Gentianaceae	*Utania volubilis*	*Mengkudu hutan*	-	14.35	-
Hypericace	*Cratoxylum cochinchinense*	*Mampat*	-	-	6.37
Lamiaceae	*Vitex pinnata*	*Alaban*	76.19	-	21.85
Moraceae	*Ficus racemosa*	*Loa*	-	24.88	-
	Ficus uncinata	*Ara bumi*	-	39.23	-
	Ficus villosa	*Ara rambat*	-	-	6.37
Rubiaceae	*Neonauclea orientalis*	*Gempol*	30.95	19.62	6.37
	Neonauclea pallida	-	61.90	-	-
	Psychotria viridiflora	*Mata udang*	-	14.35	7.74
	Urophyllum blumeanum	-	-	-	7.74
		Total number of IVI (%)	200	200	200
		Maximum IVI (%)	76.19	39.23	97.12
		Number of species	4	9	9

Note: *) the names of plants planted intentionally or revegetated plants

Table 6. IVI of woody plants at sapling level on limestone, clay, and laterite

Family	Species	Local name	Limestone	Clay	Laterite
Annonaceae	*Desmos chinensis*	*Kenanga hutan*	-	2.99	-
Apocynaceae	*Tylophora flexuosa*	-	4.96	-	3.15
Arecaceae	*Elaeis guineensis**	*Sawit*	-	6.27	-
Calophyllaceae	*Calophyllum soulattri*	*Bintangur*	-	-	18.66
Cannabaceae	*Trema cannabina*	*Anggrung*	4.96	-	-
Euphorbiaceae	*Claoxylon indicum*	*Jarak kayu*	10.51	-	-
	Croton caudatus	*Ara tanduk*	-	-	3.74
	Homalanthus populneus	*Ipo*	13.25	2.99	-
	Mabea occidentalis	-	-	2.99	-
	Macaranga gigantea	*Merkubung*	6.07	6.81	-
	Macaranga tanarius	*Sapat*	14.87	-	-
	Macaranga trichocarpa	*Sapat kecil*	8.29	7.63	-
Fabaceae	*Archidendron clypearia*	*Jengkol hutan*	-	-	6.89
	Caesalpinia crista	*Buah gorek*	-	-	22.40
Gentianaceae	*Utania volubilis*	*Mengkudu hutan*	-	7.63	-
Lamiaceae	*Vitex pinnata*	*Alaban*	22.65	2.99	22.02
Malvaceae	*Sterculia rubiginosa*	*Keradang*	12.14	2.99	-
Melastomaceae	*Dissochaeta divaricata*	*Jomak-jomak*	-	-	13.57
Moraceae	*Artocarpus odoratissimus*	*Tarap*	-	2.99	3.15
	Ficus aurata	*Ara topog*	-	-	8.07
	Ficus fulva	*Hamerang*	-	2.99	-
	Ficus racemosa	*Loa*	-	5.99	-
	Ficus sagittata	*Kirapet*	-	-	4.92
	Ficus uncinata	*Ara bumi*	-	2.99	-
	Ficus villosa	*Ara rambat*	-	-	18.66
Phyllanthaceae	*Breynia coronata*	*Hambin buah besar*	6.07	18.78	10.63
Piperaceae	*Piper aduncum*	*Sirih hutan*	24.87	24.52	3.15
	Piper kadsura	-	-	-	4.33
Rhamnaceae	*Alphitonia excelsa*	*Kalindayau*	9.91	-	-
Rosaceae	*Rubus moluccanus*	*Arbei hutan*	-	-	3.74
Rubiaceae	*Canthium horridum*	*Duri bulungan*	-	2.99	-
	Neonauclea orientalis	*Gempol*	54.27	12.54	-
	Psychotria sarmentosa	*Akar mentebel*	-	-	5.51
	Psychotria viridiflora	*Mata udang*	-	8.45	14.75
	Uncaria nervosa	*Bajakah*	-	-	3.74
Rutaceae	*Melicope confusa*	*Wangun gunung*	-	2.99	-
Verbenaceae	*Tectona grandis**	*Teak*	-	3.81	-
Vitaceae	*Leea indica*	*Girang*	7.18	-	28.91
	Leea rubra	*Girang merah*	-	67.64	-
		Total number of IVI (%)	200	200	200
		Maximum IVI (%)	54.27	67.64	28.91
		Number of species	14	21	19

Note: *) the names of plants planted intentionally or revegetated plants

The number of plant types and families mentioned above was obtained from the sample land area which is classified as very narrow, only 1.2 ha or 3.75% of the 32.0 ha of vegetated land. Although they grow and develop over a long period, namely 13 to 16 years after revegetation, the number of these species is still relatively low compared to the actual number of species in the field. We monitored the presence of other plant species that also grew and developed but outside the sample plots (Table 9). They consist of groups of revegetated or intentionally planted plants as well as groups that grow spontaneously, as are the groups of plant species in the sample plot, adding an element of unpredictability and dynamism to the ecological system. The existence of plant species outside the sample plot was also reported by Soendjoto et al. (2023a) in Kuala Tambangan Kerangas Forest, Tanah Laut District.

The presence of plants that grow spontaneously, both inside and outside the sample plot, is inseparable from the existence of the surrounding land, which is still covered by vegetation or forest. Vegetation or forests with various plant species are a source of seeds and seedlings (Graudal et al. 2021; Mejstřík et al. 2024). Soendjoto et al. (2023b) refer to plants that grow on the surrounding land and are a source of seeds or seedlings for the reclaimed land of one of the coal mining companies in South Kalimantan as mother trees. Land that has many mother trees should be looked after and maintained. The mother tree should be native because its high adaptation to the environment produces seedlings that can reduce the risk of failure in restoration or revegetation programs (Lillo et al. 2021). Existing and abundant mother trees around or outside the land have a strong influence on the presence of that plant species in revegetated land (Zahawi et al. 2021). Treating land with typical or special species is not just a step but a strategic one in preserving germplasm. Germplasm is not only an object for long-term resource management but also an investment for world civilization (Mondal et al. 2023).

Table 7. IVI of woody plants at POLE level on limestone, clay, and laterite

Family	Species	Local name	Limestone	Clay	Laterite
Anacardiaceae	*Mangifera indica**	*Mangga*	61.28	-	-
	*Spondias dulcis**	*Kedondong*	38.21	-	-
Apocynaceae	*Alstonia angustiloba*	*Pulai hitam*	-	-	61.52
Euphorbiaceae	*Macaranga gigantea*	*Merkubung*	-	70.29	-
Fabaceae	*Samanea saman**	*Trembesi*	134.22	-	-
Lamiaceae	*Vitex pinnata*	*Alaban*	-	23.53	-
Lauraceae	*Eusideroxylon zwageri**	*Ulin*	-	-	82.26
Moraceae	*Artocarpus odoratissimus*	*Tarap*	-	33.40	-
	Ficus aurata	*Ara topog*	-	68.41	-
	Ficus racemosa	*Loa*	-	19.50	-
Rhamnaceae	*Alphitonia excelsa*	*Kalindayau*	-	25.79	-
Rubiaceae	*Neonauclea orientalis*	*Gempol*	66.29	27.89	71.07
Rutaceae	*Melicope confusa*	*Wangun gunung*	-	18.30	-
Ulmaceae	*Gironniera nervosa*	*Medang berbulu*	-	-	85.15
Verbenaceae	*Tectona grandis**	*Teak*	-	12.90	-
		Total number of IVI (%)	300	300	300
		Maximum IVI (%)	134.22	70.29	85.15
		Number of species	4	9	4

Note: *) plants that are planted intentionally

Table 8. IVI of woody plants at TREE level on limestone, clay, and laterite

Family	Species	Local name	Limestone	Clay	Laterite
Apocynaceae	*Alstonia scholaris*	*Pulai putih*	-	-	10.49
	Dyera costulata	*Jelutung*	-	-	14.54
Asteraceae	*Vernonia arborea*	*Marumbung*	-	-	14.60
Calophyllaceae	*Calophyllum soulattri*	*Bintangur*	-	-	7.03
Dilleniaceae	*Dillenia reticulata*	*Sempur*	-	-	73.86
Dipterocarpaceae	*Dipterocarpus* sp.	*Kruing*	-	-	14.18
Euphorbiaceae	*Aleurites moluccana**	*Kemiri*	-	-	14.21
	Macaranga gigantea	*Merkubung*	-	41.57	21.61
	Macaranga hypoleuca	*Mahang bercak*	-	-	11.71
Fabaceae	*Acacia mangium**	*Mangium*	-	28.43	-
	*Archidendron jiringa**	*Jaring, jengkol*	-	-	7.26
	*Paraserianthes falcataria**	*Sengon*	114.60	-	-
	*Samanea saman**	*Trembesi*	185.40	-	-
Hypericaceae	*Cratoxylum chochinchinensis*	*Mampat*	-	-	7.22
Ixonanthaceae	*Ixonanthes reticulata*	*Pagar-pagar*	-	-	7.57
Lamiaceae	*Calicarpa longifolia*	*Sangkareho*	-	-	10.40
	Vitex pinnata	*Alaban*	-	-	7.05
Lauraceae	*Eusideroxylon zwageri**	*Ulin*	-	-	7.03
Malvaceae	*Hibiscus tiliaceus*	*Waru laut*	-	71.82	-
Moraceae	*Artocarpus odoratissimus*	*Tarap*	-	27.47	11.98
	Ficus aurata	*Ara topog*	-	27.83	-
Rhamnaceae	*Alphitonia excelsa*	*Kalindayau*	-	26.16	-
Rubiaceae	*Gardenia tubifera*	*Cempaka hutan*	-	-	10.79
	Neonauclea orientalis	*Gempol*	-	-	10.57
	*Neolamarckia cadamba**	*Jabon*	-	-	12.27
Sapindaceae	*Pometia pinnata**	*Matoa*	-	-	7.75
Sapotaceae	*Palaquium obovatum*	*Nyatoh*	-	-	6.70
Verbenaceae	*Tectona grandis**	*Teak*	-	76.73	11.16
		Total number of IVI (%)	300	300	300
		Maximum IVI (%)	185.40	76.73	73.86
		Number of species	2	7	22

Note: *) the names of plants planted intentionally or revegetated plants

Seed dispersal

Fruits or seeds can be spread from the mother tree to other lands through several mechanisms. There are seven ways that fruit or seeds spread (Petruzzello 2024). Four ways that are very likely to occur on the research site in the form of revegetation land are as follows.

Firstly, fruits or seeds have a distinctive morphology so they are lighter in weight and then transported and spread by the wind in all directions, including to revegetated land. The seeds of *ilalang* (*Imperata cylindrica*), *bandotan daun-kecil* (*Praxelis clematidea*), and *sawi langit* (*Vernonia cinerea*), for example, are relatively small and attached to hair-like organs that make it easy for them to be carried by the wind to land far from the parent individual (Rao et al. 2017; Intanon et al. 2020; Rusdy 2020). The fruits of various Dipterocarpaceae species have thin, elongated organs that function like wings or propellers when blown by the wind (Yang and Chen 2023). This organ helps new individuals of the plant species spread far from the mother tree (Smith et al. 2015).

Secondly, fruits are food for animals, such as mammals (squirrels, bats, civets) or birds (Handayani 2022). After the fruit is eaten or swallowed by the animal, the undigested seeds are stored in the feces, which are then excreted from the animal's body and left in the revegetation area. Apart from feces, seeds can also be vomited in revegetated areas after animals suck the flesh. This behavior is observed in small birds: *cabe jawa* (*Dicaeum trochileum*) or *cabe bunga-api* (*D. trigonostigma*), medium-sized birds: *cucak kutilang* (*Pycnonotus aurigaster*) or *merbah cerucuk* (*P. goiavier*), and large birds: *kangkareng perut-putih* (*Anthracoceros albirostris*). This avifauna is spread throughout the South Kalimantan region, from the inland to the coast (Soendjoto et al. 2018; Riefani and Soendjoto 2021), such as the ITP-12 operational area which is located on the northeastern coast of the South Kalimantan Province (Riefani et al. 2019).

Thirdly, the fruit explodes and throws the seeds far from the mother tree (Cullen and Hay 2024). According to Parolin et al. (2013), *Hevea* is one genus that carries out such a mechanism. If so, then rubber (*Hevea brasiliensis*) could be an example of a parent tree with this mechanism in this study, even though it was observed growing outside the sample plot (Table 9).

Lastly, fruits or seeds are stored naturally in topsoil or other soil layers, which then act as a seed bank (Shiferaw et al. 2018; Yang et al. 2021). When soil is temporarily moved to another land or permanently returned to revegetation land, seeds can continue their dormancy or grow and develop into new individuals. *Ulin* (*E. zwageri*), a monotypic species with vulnerable status (IUCN 2024) produces seeds with a long dormancy period (Puspaningrum et al. 2013). To break dormancy, ironwood is soaked in a liquid containing sodium nitrophenolate at a certain concentration (Purba et al. 2019).

Similarities and diversity of plants

Almost all plant community similarity indices between ex-mining land for certain raw materials and ex-mining land for other raw materials are at a value of ≤0.50 (Table 10). There are two similarity indices whose value is >0.50, namely the herbaceous community on limestone versus clay and the herbaceous community on limestone versus laterite. This indicates that plant communities on ex-mining land for certain raw materials possess unique characteristics that distinguish them from those in ex-mining land for other raw materials. This dissimilarity is reflected by the presence of different plant species on each raw material ex-mining land (Tables 2-8) or the level of plant community diversity (Figure 3).

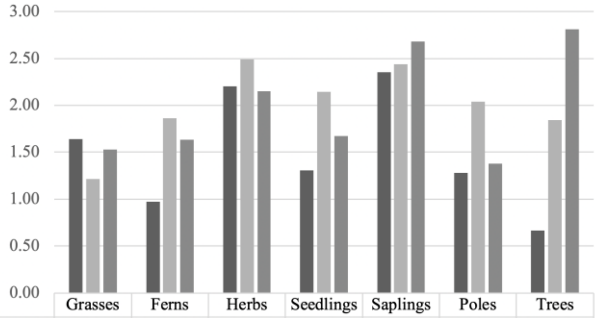
Table 9. Several plant species were observed growing and developing outside the sample plots

Family	Species	Local name
Revegetation plants (intentionally planted)		
Anacardiaceae	*Mangifera casturi*	*Kasturi*
Combretaceae	*Terminalia catappa*	*Ketapang*
Fabaceae	*Calliandra calothyrsus*	*Kaliandra*
Fabaceae	*Pterocarpus indicus*	*Angsana*
Musaceae	*Musa paradisiaca*	*Pisang kepok*
Sapindaceae	*Dimocarpus longan*	*Klengkeng*
Spontaneously growing plants		
Annonaceae	*Polyalthia lateriflora*	*Banitan*
Asteraceae	*Mikania micrantha*	*Sambung rambat*
Cannabaceae	*Trema tomentosa*	*Mengkirai*
Euphorbiaceae	*Hevea brasiliensis*	*Karet*
Euphorbiaceae	*Mallotus paniculatus*	*Balik angin*
Lamiaceae	*Clerodendrum* sp.	-
Lamiaceae	*Gmelina arborea*	*Jati putih*
Malvaceae	*Commersonia bartramia*	*Blencong*
Myrtaceae	*Syzygium zeylanicum*	*Nasi-nasi*
Myrtaceae	*Syzygium acuminatissimum*	*Pitaruk*
Myrtaceae	*Syzygium polianthum*	*Salam*
Phyllanthaceae	*Breynia vitis-idaea*	*Mangsian*
Poaceae	*Bambusa vulgaris*	*Bambu kuning*
Rubiaceae	*Morinda citrifolia*	*Mengkudu*
Verbenaceae	*Lantana camara*	*Tembelekan*

Note: Rubber is included as a spontaneously growing plant. This sap-producing cultivated plant is commonly planted by the community but not planted by ITP

Table 10. Index of similarity of plant communities between certain ex-mining land and other ex-mining land

Ex-mining land	Grasses	Ferns	Herbs	Seedlings	Saplings	Poles	Trees
Limestone vs Clay	0.50	0.29	0.56	0.31	0.46	0.15	0.00
Limestone vs Laterite	0.36	0.31	0.56	0.31	0.30	0.25	0.00
Clay vs Laterite	0.36	0.48	0.48	0.22	0.25	0.15	0.21



	Grasses	Ferns	Herbs	Seedlings	Saplings	Poles	Trees
Limestone	1.64	0.97	2.20	1.31	2.35	1.28	0.67
Clay	1.22	1.86	2.49	2.15	2.44	2.04	1.84
Laterite	1.53	1.63	2.15	1.67	2.68	1.38	2.81

Figure 3. Diversity index according to plant communities on each ex-mining land

The main cause of dissimilarity is edaphic factors in terms of the physical, chemical, and biological properties of the soil. Plant communities utilize soil as a source of nutrients (Neina 2019; Głąb 2023; Tagele et al. 2023; Bhat et al. 2024). They are different because the type of soil in the form of limestone, clay, or laterite that they use to live and as a source of nutrition contains main components or compounds that are different from each other (Zaliha et al. 2015; Satpudke and Ashutkar 2016; Hwidi et al. 2018). This difference can also occur in biological factors contained in the type of soil.

The physical and chemical properties of each type of soil change after mining. In Banyumas, post-mining limestone soils have low fertility and slightly alkaline pH (Harwanto et al. 2023). Mining in karst in Citatah, Bandung, reduces the physical, chemical, and biological quality of soil fertility (Humaeriyah and Romadhona 2018). After mining in North Konawe District, Southeast Sulawesi, the profile of nickel laterite deposits changed (Mustafa et al 2023), and this change was indicated by the Lambuluo River, which was polluted by heavy metals (Ngkoimani and Chaerul 2017). In Kenya, laterite excavation causes land degradation, environmental pollution, and loss of biodiversity (Samson et al. 2021). According to Mensah (2015), soil is degraded through processes or mechanisms of soil structure destruction, accelerated erosion, excessive soil leaching, reduced pH, accumulation of heavy metals, removal of organic matter and nutrients, reduced activity of microorganisms, and reduced cation exchange capacity.

During reclamation, the topsoil should not simply be returned to ex-mining land. The soil layer, especially the topsoil, needs to be selected and supplemented with materials that improve quality, such as organic matter, manure, and fertilizer (Pratiwi et al. 2021). The quality of topsoil is important (Turrión et al. 2021). Changes are very likely to occur as long as the top layer of soil is in temporary storage before finally being returned to reclaimed land and ready for revegetation. In temporary landfills, the top layer of soil undergoes various kinds of treatment, both natural (such as being eroded, washed away by rainwater, and exposed to sunlight) and anthropogenic (such as planting cover crops, making land for cultivating short-lived crops).

The next cause of dissimilarity is climatic factors, natural (environmental) factors that cannot be controlled. In the period from 13 to 16 years after revegetation, plants experienced fluctuations due to differences in environmental factors (including temperature, humidity, wind speed, and light intensity) between lands. Short-lived plants (such as grasses, ferns, or herbs) are certain to die soon after living for only a few months or years. Woody plants planted at the seedling stage gradually reach the level of saplings, poles, and even trees. *Acacia mangium* reaches a diameter of 25 cm at the age of 8 years (Krisnawati et al. 2011a), *P. falcataria* in Ciamis reaches a minimum of 24.6 cm at the age of 12 years (Krisnawati et al. 2011b), and *T. grandis* in India 26.9 cm between 15-20 years (Rajah et al. 2023). At the same time, spontaneously growing plant species emerge and compete for space (land) and time. These plants include *Ficus* (Azhari et al. 2024) as well as *Alstonia scholaris, Homalanthus populneus*, and *Macaranga gigantea*, which are known as pioneer plants (Sasmita et al. 2020).

In conclusion, of the 155 plant species found in ex-mining land for cement raw materials, the majority (90.32%) grow spontaneously. The plant species that dominate the plant community in each area are different. Almost all plant communities on certain land are not similar to those on other land. Only the herbaceous plant communities in limestone and clay are similar, with the highest similarity index, even though it is only 0.56. Because the plant diversity index at tree level is the highest in laterite, this land is considered the most suitable for various plant species at tree level. This data collection is the first since revegetation 13 to 16 years ago so the results can be used as basic data or comparison for subsequent measurement data.

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