FLORA COMPOSING UNDERSTORY VEGETATION OF FORMER BAUXITE MINING LAND IN TANJUNGPINANG, RIAU ISLANDS, INDONESIA †

[FLORA QUE COMPONE LA VEGETACIÓN DE SOTOBOSQUE EN TIERRAS PREVIAMENTE EMPLEADAS COMO MINAS DE BAUXITA EN TANJUNGPINANG, ISLAS RIAU, INDONESIA]

Erda Muhartati[1,2], **Andhika P-Nugroho**[3], **Diah Rachmawati**[4] **and Purnomo**[5*]

[1]*Biology Doctoral Program, Faculty of Biology, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia. Email: muhartatierda@gmail.com*,*
[2]*Biology Education, Faculty of Teacher Training and Education, Universitas Maritim Raja Ali Haji, Tanjungpinang, 29124, Indonesia. Email: muhartatierda@gmail.com* *
[3]*Faculty of Biology, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia. Email: andhika_pn@ugm.ac.id*
[4]*Department of Tropical Biology, Faculty of Biology, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia. Email: drachmawati@ugm.ac.id*
[5]*Laboratory of Plant Systematics, Faculty of Biology, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia. Email: purnomods@ugm.ac.id* *
** Corresponding author*

SUMMARY

Background. The aim of this research is to identify plant species that constitute the vegetation and species abundance in ex-bauxite mining land in Tanjungpinang City, Riau Islands Province, Indonesia. **Objective**. To identify vegetation composition and species abundance on ex-bauxite mining land. **Methodology** A nested plot sampling method was used to randomly identify the species at two ex-bauxite mining sites (Dompak and Senggarang) and a non mining site in Senggarang. Each site, measuring 1x1 meter, with 12, 14, and 12 plots were also examined using the understory plant samples. Furthermore, observations were made on the morphological characteristics of plants to determine the herbarium preparation process, identify the species, and validate the scientific names of plants. **Results.** The research found that understory plants in the three sites consisted of 17 families with 24 species with the Cyperaceae family contributing five more species than any other families. The three species with the highest importance value indices at each site were: at Dompak namely, Poaceae (51%), *Waltheria indica* (26.50%), and *Dicranopteris linearis* (21.80%); at Senggarang, *Palhinhaea cernua* (37.10%), *D. linearis* (37.02%), and Poaceae (36.37%); and the not a former bauxite mine site in Senggarang is *D. linearis* (70,00%), Poaceae (64.00%), and *Melastoma malabathricum* (23.07%). The Sorensen similarity index values for the three locations were 46.7% for the Dompak and Senggarang sites, 41.7% for the Dompak site and the non-former bauxite mining site, and 50% for the Senggarang site and the non-former bauxite mining site, respectively. **Implications.** Morphological species identification and herbarium preparation were used to identify and validate the vegetation composition on the former bauxite mining land in Tanjungpinang. The data obtained is valuable for understanding the natural recovery patterns of the land and provides insight into species suitable for further rehabilitation in the Riau Islands. The result showed that invasive species such as Poaceae and *Dicranopteris linearis* should be prioritized in revegetation programs. The research also addresses a gap in scientific knowledge regarding critical species for the successful rehabilitation of degraded lands. **Conclusion.** The research found that understory plants in the three sites consisted of 17 families with 24 species. The importance value index at each site was 51% for Poaceae (at Dompak), 37.10% for *P. cernua* (at Senggarang), and 70% for *D. linearis* (at non-former bauxite mine site in Senggarang). The Sorensen similarity index values for the three sites were 46.7%, 41.7%, and 50% for the Dompak and Senggarang sites, Dompak, and the non-former bauxite mining sites.
Key words: understory-vegetation; bauxite; indonesia; species; important-value-index; similarity-index.

RESUMEN

Antecedentes. El objetivo de esta investigación es identificar las especies de plantas que constituyen la vegetación y la abundancia de especies en tierras ex mineras de bauxita en la ciudad de Tanjungpinang, provincia de las islas Riau, Indonesia. Objetivo. Identificar la composición de la vegetación y la abundancia de especies en tierras ex

† *Submitted November 19, 2024 – Accepted January 22, 2025. http://doi.org/10.56369/tsaes.6009*

ISSN: 1870-0462.
ORCID = E. Muhartati: https://orcid.org/0000-0002-0607-7098; **A. P-Nugroho**: https://orcid.org/0000-0001-7772-7708; **D. Rachmawati**: https://orcid.org/0000-0003-3162-4089; **Purnomo**: https://orcid.org/0000-0002-3618-2083

mineras de bauxita. Metodología Se utilizó un método de muestreo de parcelas anidadas para identificar aleatoriamente las especies en dos sitios ex mineros de bauxita (Dompak y Senggarang) y un sitio no minero en Senggarang. Cada sitio, que mide 1x1 metro, con 12, 14 y 12 parcelas también se examinaron utilizando las muestras de plantas del sotobosque. Además, se realizaron observaciones sobre las características morfológicas de las plantas para determinar el proceso de preparación del herbario, identificar las especies y validar los nombres científicos de las plantas. Resultados. La investigación encontró que las plantas del sotobosque en los tres sitios consistían en 17 familias con 24 especies, y la familia Cyperaceae contribuía con cinco especies más que cualquier otra familia. Las tres especies con los índices de valor de importancia más altos en cada sitio fueron: en Dompak, a saber, Poaceae (51%), Waltheria indica (26,50%) y Dicranopteris linearis (21,80%); en Senggarang, Palhinhaea cernua (37,10%), D. linearis (37,02%) y Poaceae (36,37%); y el sitio que no es una antigua mina de bauxita en Senggarang es D. linearis (70,00%), Poaceae (64,00%) y Melastoma malabathricum (23,07%). Los valores del índice de similitud de Sorensen para las tres ubicaciones fueron 46,7% para los sitios de Dompak y Senggarang, 41,7% para el sitio de Dompak y el sitio que no es una antigua mina de bauxita, y 50% para el sitio de Senggarang y el sitio que no es una antigua mina de bauxita, respectivamente. Implicaciones. La identificación de especies morfológicas y la preparación de herbario se utilizaron para identificar y validar la composición de la vegetación en la antigua tierra minera de bauxita en Tanjungpinang. Los datos obtenidos son valiosos para comprender los patrones de recuperación natural de la tierra y brindan información sobre las especies adecuadas para una mayor rehabilitación en las Islas Riau. El resultado mostró que las especies invasoras como Poaceae y Dicranopteris linearis deben priorizarse en los programas de revegetación. La investigación también aborda una brecha en el conocimiento científico con respecto a las especies críticas para la rehabilitación exitosa de tierras degradadas. Conclusión. La investigación encontró que las plantas del sotobosque en los tres sitios consistían en 17 familias con 24 especies. El índice de valor de importancia en cada sitio fue del 51% para Poaceae (en Dompak), 37,10% para P. cernua (en Senggarang) y 70% para D. linearis (en el sitio que no fue una antigua mina de bauxita en Senggarang). Los valores del índice de similitud de Sorensen para los tres sitios fueron 46,7%, 41,7% y 50% para los sitios de Dompak y Senggarang, Dompak y los sitios de extracción de bauxita no antiguos.
Palabras clave: vegetación del sotobosque; bauxita; Indonesia; especies; índice de valor importante; índice de similitud.

INTRODUCTION

The loss of topsoil is a characteristic of poor soil fertility in ex-mining land (Wibowo *et al*., 2020). The reaction process shows the acidity of the soil determined by the pH value. In line with this result, the pH value also played a significant role in ascertaining how easily plants absorb nutrients, suggesting the possibility of toxic elements in the soil (Hardjowigeno, 2010).

Plants experience nutrient deficiencies due to lack or slightly dissolved quantities of these elements present in the soil. In this regard, Windusari *et al.*, (2011), reported that several successional vegetation covered post-mining land areas. These included grasslands, trees, and transitional vegetation types as well as secondary forests. According to López-Vicente *et al*., (2020), the use of cover plants contributed to reducing the loss of organic matter, and also regarded as an efficient regulatory strategy. Understory vegetation is a group of plants covering the soil layer under tree stands. Its life forms are characterized by solitary, clumped, upright, and creeping or climbing movements (Sefmaliza & Chairul, 2022).

Based on the description above, vegetation composition indicators refer to the number of plant species present in an ecosystem whose existence is influenced by various factors enabling its adaptation. However, open mining damages the surface structure of the soil which contains nutrients rich in minerals (Purwanto *et al*., 2019).

Previous research reported that the presence of plant species in an area showed the adaptation ability and wide tolerance to the habitat and environmental conditions (Soegianto, 1994). Pioneer species increased soil fertility by producing root exudates that attract certain bacteria. This resulted in microclimatic conditions and the prevention of erosion due to the ability of the root system to hold the soil (Lee *et al*., 2020).

Vegetation other than the natural ones in ex-mining sites requires attention due to its ability to restore the productivity of degraded land. Moreover, Senggarang and Dompak, are known for its prospective mining and fisheries sectors. Several of these sites were damaged due to bauxite mining activities, with the constituent species in ex-bauxite mines realized from the surrounding plants.

This research examined the role played by natural regeneration and pioneer species in post-mining ecosystem recovery, documented local biodiversity essential for effective reclamation programs and degraded land (Prach & Pyšek, 2001). It also evaluated the lack of similar investigations in the region, reinforced the scientific novelty and relevance of the results for local environmental management. Furthermore, the research analyzed the deficits of plant species identification and vegetation abundance in post-bauxite mining sites in Tanjungpinang, which showed the need for the use of long-term data to conduct site-specific investigations, with emphasis on emphasis on ecological interactions between species. The use of GAP analysis to identify the abundance of plant species identification and vegetation showed that long-term data and site-specific investigations need to be improved, while significantly considering ecological interactions (Van Andel & Aronson, 2012). The current research focused on the significance of multidisciplinary methods and practical recommendations for reclamation, and outlined the minimal participation of local communities in land restoration. Multidisciplinary methods were rarely applied, which resulted in the lack of comprehensive understanding. Previous investigations failed to provide practical recommendations for reclamation, including the minimal participation of local communities in land restoration (Parrotta *et al*., 2012). This led to the need for improvements in long-term monitoring, participatory reclamation programs, and a more comprehensive understanding of ecological processes. Generally, the research results were in line with the broader objective of integrating sustainable practices into ecosystem restoration, outlining the relevance of considering both ecological and social factors.

The aim of this research is to identify plant species that constitute the vegetation and species abundance in ex-bauxite mining land in Tanjungpinang City, Riau Islands Province, Indonesia.

MATERIALS AND METHODS

Study zone

The current research was conducted at former bauxite mines in Senggarang and Dompak with coordinates (Latitude 0°57'7.18"N and Longitude 104°25'47.93"E), and (Latitude 0°52'23.93"N and Longitude 104°31'12.16"E), respectively. It was also conducted at not a former bauxite mine in Senggarang with coordinates (Latitude 0°57'24.72"N and Longitude 104°25'47.52"E), and all three sites were located in the Tanjungpinang City site, Riau Islands Province, Indonesia. At the Senggarang site, the air temperature and humidity ranged from 32.9oC-43.5oC, and 42%-71%, respectively. Meanwhile, at the Dompak site, the air temperature and humidity ranged from 29.3oC-33.4oC, and 64%-93%. At the not former bauxite mine site in Senggarang, the air temperature and the humidity were within 29.6oC-36.6oC, and 61%-83%. The Senggarang, Dompak, and not former bauxite mine site in Senggarang site is clay; at the Dompak site, it has a sandy loam texture; and at the not former bauxite mine site in Senggarang had clay, sandy loam, and clay soil textures, respectively.

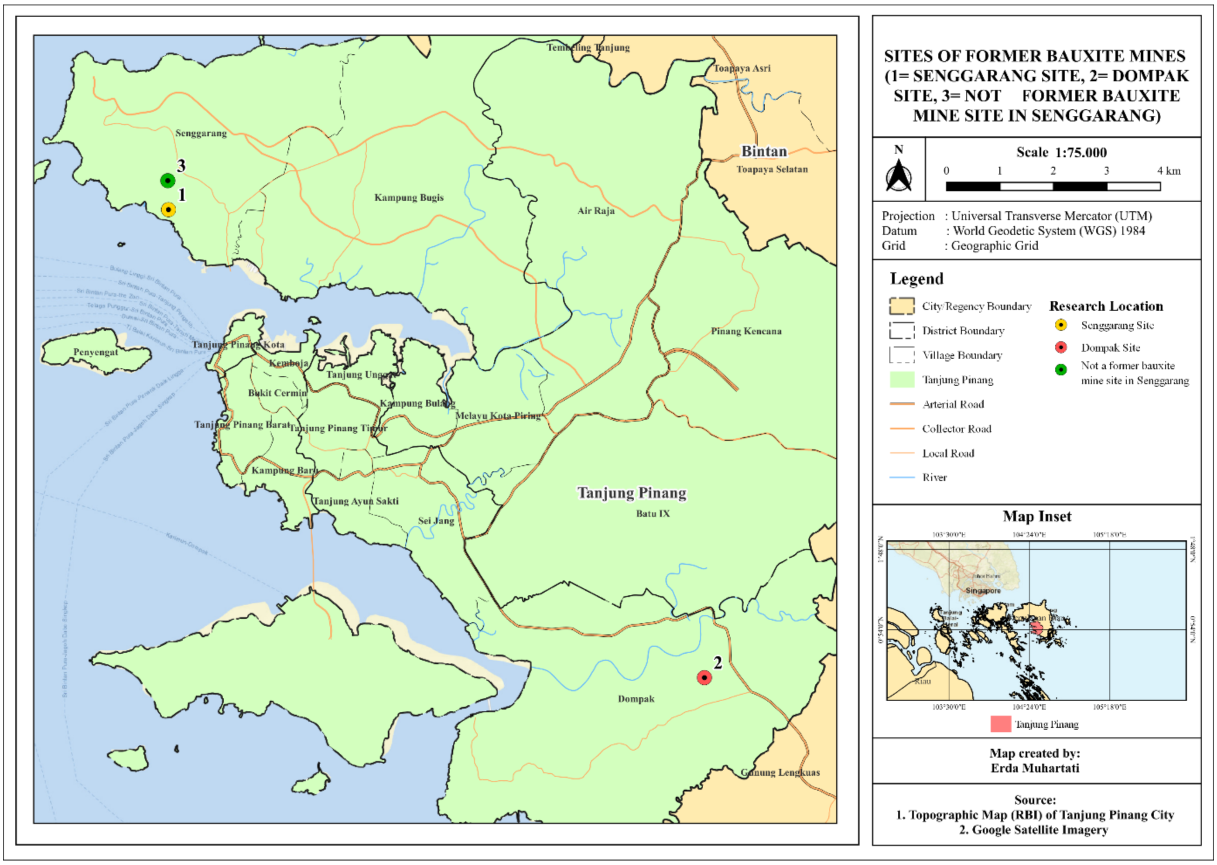

Figure 1 Sites of former bauxite mines (1= Senggarang site, 2= Dompak site, 3= Not a former bauxite mine site in Senggarang).

Methods

The data collection was carried out using a random sampling method by determining the area of the nested plot with a size of 1x1 m. At the former bauxite mining locations in Dompak, and Senggarang, including the former bauxite mine site in Senggarang there were 12 plots, and 14 plots, and 12 plots. Furthermore, undergrowth was collected from the research sites and photographed to capture its structural details, with the visible characteristics, including leaf traits and notable features, were documented. Herbarium specimens were prepared by pressing and drying following standard protocols for future reference. Specimens were identified with the help of the Flora of Java book (Backer and van den Brink, 1963-1968) and the Flora Malesiana book (Steenis, 1978). Validation of the scientific names of the plants found can be seen on the ITIS (Integrated Taxonomic Information System), POWO (Plants of the World Online), and Plantlist websites. Matching plant images using the Flora book (Steenis, 2006).

Data analysis

Data analysis for the three sites was conducted both qualitatively and quantitatively. The qualitative analysis required describing and identifying species, alongside determining the mechanism for undergrowth. The quantitative analysis also focused on explaining the important value index by calculating density (D), relative density (RD), frequency (F), and relative frequency (RF). According to Cox (1978), the RD and RF data were used to estimate abundance, also determined from the important value index (IVI). The species similarity index was also calculated using Sorensen's similarity index (SI) formula (Odum, 1997). The following are some formulas used for data analysis:

$$D = \frac{\text{Number of individuals of a species}}{\text{Plot area}}$$

$$RD = \frac{\text{Density of a species}}{\text{Density of all species}} \times 100\%$$

$$F = \frac{\text{Number of plots where a species was found}}{\text{Total Number of observation plots}}$$

$$RF = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} 100\%$$

$$IVI = RD + RF$$

$$SI = \frac{\text{2j (represents the number of species found in both locations)}}{\text{a (is the number of species found at location a)+b (is the number of species found at location b)}}$$

RESULTS

Plant species that make up the vegetation (flora) below the former bauxite mine

The flora or vegetation found below the former bauxite mines consisted of several plant species. After identification, 24 species were obtained, belonging to 17 Families of Spermatophyta and Pteridophyta, as shown in Table 1.

The abundance of species that make up the vegetation (flora) below the former bauxite mine

The following data RD, RF, and IVI were calculated in percent (%), alongside SI, as shown in the Tables 1–5.

DISCUSSION

The research reported that the families with the third highest IVI in the Dompak site were Poaceae, Malvaceae, and Gleicheniaceae. At the former bauxite mining location in Senggarang, the families

Table 1. Data on relative density, relative frequency, and importance index of plants from former bauxite mines at the Dompak site

No	Species	Family	RD	RF	IVI
1	Poaceae	Poaceae	33.40	17.00	51.00
2	*Waltheria indica*	Malvaceae	21.50	5.00	26.50
3	*Dicranopteris linearis*	Gleicheniaceae	11.80	10.00	21.80
4	*Ploiarium elegans*	Bonnetiaceae	15.00	5.00	20.00
5	*Rottboellia cochinchinensis*	Poaceae	5.90	12.50	18.40
6	*Nepenthes gracilis*	Nepenthaceae	3.20	10.00	13.20
7	*Carex otrubae*	Cyperaceae	2.30	7.50	9.80
8	*Melastoma malabathricum*	Melastomataceae	1.60	5.00	6.60
9	*Ageratum conyzoides*	Asteraceae	0.70	2.50	3.20
10	*Dianella ensifolia*	Asphodelaceae	0.50	2.50	3.00
11	*Commersonia bartramia*	Malvaceae	0.40	2.50	2.90
12	*Doliocarpus multiflorus*	Dilleniaceae	0.40	2.50	2.90
13	*Palhinhaea cernua*	Lycopodiaceae	0.40	2.50	2.90
14	*Adinandra dumosa*	Pentaphylacaceae	0.20	2.50	2.70
15	*Cassytha filiformis*	Lauraceae	0.20	2.50	2.70
16	*Populus tremuloides*	Salicaceae	0.20	2.50	2.70
17	*Verbascum blattaria*	Scrophulariaceae	0.20	2.50	2.70
	Number		100.00	100,00	200,00

Table 2. Data on relative density, relative frequency, and importance index of plants from the former bauxite mine at the Senggarang site.

No	Species	Family	RD	RF	IVI
1	*Palhinhaea cernua*	Lycopodiaceae	22.22	14.88	37.10
2	*Dicranopteris linearis*	Gleicheniaceae	24.26	12.76	37.02
3	Poaceae	Poaceae	17.23	19.13	36.37
4	*Carex otrubae*	Cyperaceae	7.03	12.76	19.78
5	*Carex* L.	Cyperaceae	7.26	10.63	17.89
6	*Lepironia articulata*	Cyperaceae	9.52	4.25	13.78
7	*Curculigo capitulata*	Hypoxidaceae	7.71	2.13	9.84
8	*Nepenthes gracilis*	Nepenthaceae	0.91	6.38	7.28
9	*Melastoma malabathricum*	Melastomataceae	0.68	6.38	7.06
10	*Digitaria* sp.	Poaceae	2.04	4.25	6.29
11	*Cassytha filiformis*	Lauraceae	0.68	2.13	2.81
12	*Grona triflora*	Fabaceae	0.23	2.13	2.35
13	*Gahnia tristis*	Cyperaceae	0.23	2.13	2.35
Number			100.00	100.00	200.00

Table 3. Data on relative density, relative frequency, and importance index of ex-bauxite mining plants in not a former bauxite mine site in Senggarang.

No	Species	Family	RD	RF	IVI
1	*Dicranopteris linearis*	Gleicheniaceae	45.03	24.97	70.00
2	Poaceae	Poaceae	29.67	34.33	64.00
3	*Melastoma malabathricum*	Melastomataceae	13.71	9.36	23.07
4	*Carex otrubae*	Cyperaceae	3.37	12.48	15.85
5	*Carex* L.	Cyperaceae	5.90	9.40	15.30
6	*Dianella ensifolia*	Asphodelaceae	1.26	3.12	4.38
7	*Cyperus aromaticus*	Cyperaceae	0.21	3.12	3.33
Number			100.00	100.00	200.00

Table 4. Similarity index data of the three sites.

No	Site pair	Shared species	Sorensen's similarity index (SI)	Similarity percentage
1	Dompak and senggarang	7	0.467	46.7%
2	Dompak and not a former bauxite mine site	5	0.417	41.7%
3	Senggarang and not a former bauxite mine site	5	0.5	50%

Table 5. Diversity and evenness index values at the three sites.

No	Sites	Diversity index	Evenness index
1	Former Bauxite Mine Site in Dompak	1.95 (moderate)	0.66 (high)
2	Former Bauxite Mine Site in Senggarang	1.99 (moderate)	0.78 (high)
3	Not a former bauxite mine site	1.27 (moderate)	0.65 (high)

with the highest IVI included Lycopodiaceae, Gleicheniaceae, and Poaceae. However, at the bare Senggarang site, the families with the highest IVI consisted of Gleicheniaceae, Poaceae, and Melastomataceae. The data showed that the Poaceae family was consistently found across all three sites, indicating strong dominance in these ecosystems.

Poaceae, commonly known as grasses, played a crucial role in ecosystem restoration and degradation. According to Wulandari *et al*., (2017), its identification is essential for assessing the progress of degraded grassland restoration. Poaceae is also a natural greening agent that reduces pollutants and maintains environmental balance. Bohari and Baiq (2015), stated that grasses were responsible for improving and sustaining the microclimate, as well as enhancing aesthetic value, supporting water catchment areas, and promoting environmental harmony. Based on its ability to thrive in open and protected areas, Poaceae exhibited highly adaptable characteristics to tropical and subtropical regions. In line with this result, grasses were observed to grow in clumps and rarely found isolated.

The ecological significance of Poaceae extended to its conservation, essential for sustainability and future use (Solikin, 2004). Tjitrosoepomo (2009), reported that this species relied on wind for pollination due to the lightweight flower structures. Wind speed played a crucial role in seed dispersal, influencing its spread. Despite the adaptability to various environmental conditions, there was a decline in Poaceae due to increased reclamation efforts, which inhibited the growth and development process (Arisandi *et al*., 2015). However, its resilience enabled the ability to withstand drought and waterlogging, with the dense foliage functioning as an erosion barrier, stabilizing soil and sediment (Sittadewi, 2008).

Given these characteristics, Poaceae was often recommended in terms of restoring contaminated lands (Patra *et al*., 2021). The ability to thrive in diverse habitats makes it one of the most successfully adapted land plants (Arisandi *et al*., 2019). Its family exhibited a wide range of life forms, from short to long-lived species, from short-lived to long- lived species, and the adaptability features were influenced by environmental conditions. Furthermore, Poaceae has a high tolerance for different soil types, further supporting the ecological success.

Another crucial aspect of Poaceae's dominance is the ability to withstand grazing. Ezcurra (2020), reported that the basal organization of grass culms allowed for regrowth even after herbivores consumed the aerial parts of the plant. Consequently, grasses were abundantly found in sub-humid and semi-arid open woodlands, with its rapid spread influenced by human activities, climate, agronomic practices, and absence of natural predators (Ellison & Evans, 1992). Seed dispersal mechanisms significantly affected the distribution process. Wenny (2001), also stated that many wind-dispersed species were shade-intolerant, and required open gaps for germination. Moreover, directional dispersal patterns favoured generalist plants with small, attractive, and abundant fruits. (Da Silva *et al*., 1996).

Compared to Poaceae, Malvaceae exhibited a different dispersal strategy. This family mainly relied on passive seed dispersal and vegetative reproduction, assisted by wind, water, and animals. Insects played a major role in pollination, with flowers rich in nectar attracting pollinators such as bees and butterflies (Kartika & Humaira, 2023). Malvaceae also contributes to ecosystems by providing habitat and food sources for various organisms, including birds and small mammals that consumed its fruits and seeds.

Malvaceae belong to a family comprising diverse herbs, shrubs, and trees, predominantly found in tropical and subtropical regions, with some genera extending to temperate zones, as reported by Fryxell (2000). The Royal Botanic Gardens & Domain Trust (n.d.) further outlined that this species had a cosmopolitan distribution, except in extremely cold regions. The seeds, which were either winged, downy, or lacked additional structures, varied in endosperm content. In addition, several species belonging to its family were cultivated as ornamental plants due to the attractive flowers (Tang *et al*., n.d.).

The dispersal mechanisms of Malvaceae varied, and according to Bekele (2017), its seeds were distributed through water, agricultural equipment, and grazing animals. Polunin (1994), further stated that seeds or fruits dispersed internally by animals were brightly colored, juicy, and protected by durable sheaths to withstand digestion. This method of dispersal can be categorized into two types, namely external (ectozoic or epizoic) and internal (endozoic) (Polunin, 1994). Additionally, grasslands, including those dominated by Poaceae and Asteraceae, were often characterized by autonomic and anemochoric species (Sádlo *et al*., 2018).

The following species Poaceae, Malvaceae, Gleicheniaceae, and Lycopodiaceae belong to the fern families commonly found in former bauxite mining areas. The Gleicheniaceae, particularly *Dicranopteris linearis*, exhibited a herbaceous features and was known for its passive wind-assisted spore dispersal and active vegetative reproduction. According to Sádlo *et al*., (2018), this strategy relied on light and small spores transported by various vectors. De Lange (2013), stated that *D. linearis* had long creeping rhizomes covered in hairs, while Allan (1961) described the distribution process across tropical and temperate regions of the Southern Hemisphere. Gleicheniaceae belong to an ancient fern family with fossil evidence dated back to the Permian period (Skog, 2001).

Phlegmariurus cernua, belonging to the family Lycopodiaceae, is another similar species that adapted to various topographical conditions. In the Senggarang lowland area (1-5 masl), *P. cernua* and *D. linearis* were found, while in the higher non-mining areas (19-28 masl), only *D. linearis* was observed. Additionally, both species were found at the Dompak site (1-5 masl). The distribution process suggested that these ferns were properly adapted to tropical and subtropical environments across Asia and the Pacific (WFO, 2024). Lycopodiaceae, known for its wide habitat range, had various life forms namely vines, semi-aquatic, and robust terrestrial plants (Arana *et al*., 2017). Brownsey and Perrie (2020) further stated that Lycopodiaceae belonged to a cosmopolitan family with its greatest diversity that Lycopodiaceae is a cosmopolitan family with its greatest diversity observed in humid montane forests and tropical alpine regions.

Another important family present in these ecosystems is Melastomataceae, characterized by a unique combination of passive and active dispersal mechanisms. The seeds were passively dispersed, and its vegetative parts actively propagated. Regarding this perspective, the seed distribution process mainly relied on animals and wind. Birds, for example, contributed to the dispersal process by consuming and excreting the seeds of fruits (Cleland, n.d.). Renner (1993), reported that Melastomataceae is a large family consisting of approximately 166 genera and 4,200 to 4,500 species, predominantly concentrated in the New World.

Melastomataceae belongs to an exclusively tropical family, with relatively 3,600 species distributed across 100 genera in the Neotropics. Approximately 100 species belong to vines, lianas, or epiphytic climbers. These plants are the most diverse in moist tropical forests, covering from sea level to high-altitude mountainous regions. Its ecological role extends beyond dispersal, contributing to biodiversity and vegetation dynamics in respective habitats (Michelangelo, 2018).

Certain types of Melastomataceae species are invasive in tropical and subtropical environments outside the native range (iNaturalist, n.d.). According to Nesom (2022), these were characterized by the prominent venation on the opposite leaves, radially symmetrical flowers, and anthers that die at the tip. anthers that die at the tip. These traits, including the adaptability attributes, enabled Melastomataceae species to thrive in various ecological conditions.

Table 1 in the supplementary file, shows that 17 families and 24 species, were found. This information played a relevant role in determining local diversity, as well as increasing the ecosystem's complexity and stability. Additionally, the discovery of new flora, such as pioneer undergrowth and stability. The discovery of new flora, such as pioneer undergrowth vegetation on degraded soil, was beneficial in the recovery process of the area.

The undergrowth plants were reportedly unevenly distributed in all observation areas, certain types only accumulated in either one or a few plots. The Sorensen similarity index values for the three locations were as follows: 46.7% for the Dompak and Senggarang sites, 41.7% for the Dompak site and the non-former bauxite mining site, and 50% for the Senggarang site and the non-former bauxite mining site. Compared to the *L. articulata* found along wet former bauxite mining sites, transitioned into pools, and not-former bauxite mining site, the following species *N. gracilis.* Poaceae, *M. malabathricum*, *C. otrubae*, and *D. linearis* were detected in all three sites. Soil water content and pH at the Dompak location were within the range of 0.5 mm (0.89%-2.00%, to 2 mm (0.75%-1.11%), and (3.85-4.68), respectively. At the Senggarang location the water content and pH ranged from 0.5 mm (2.56%-3.75), to 2 mm (2.47%-3.45%), and (3.85-4.08). The non-ex-bauxite mining locations had water content and pH within 0.5 mm (1.36%-1.88%), to 2 mm (0.98%-1.22%), and (3.85-4.23), respectively. Wind speed in Tanjungpinang ranged from 5 to 44 km/hour and was perceived as strong. In the field, strong winds were observed, hence the distribution process was partly assisted by wind, stagnant water in the former bauxite mining site, and several types of birds, dragonflies, flies, ants, as well mosquitoes, snakes, and crocodiles. The resilience of species in former bauxite mining sites were evident, as several others produced flowers, including *M. malabathricum*, various grass species, *L. articulata*, *A. conyzoides*, *W. indica*, *V. blattaria*, and *C. bartramia*. The species also exhibited terrestrial life forms, except for *L. articulata*, which showed hydrophytic and hygrophytic growth.

Asides from the description above, high concentrations of Al ions were commonly found in acidic soils (low pH). These ions also aid in fixing phosphorus (P), ensuring its unavailability and acting as toxins to the roots (Purwanto *et al*., 2019). Meanwhile, low soil pH and CEC were regarded as significant challenges in mining sites. Acidic soils required additional treatment and careful selection of plant species. The indirect changes in the physical and chemical properties of the soil led to a decline in fauna, bacteria, fungi, and mycorrhizae populations. Former mining sites were generally infertile, and lack of organic matter resulted in low pH, high clay content, or poor nutrient availability (Hartati & Sudarmadji, 2016; Feng *et al*., 2019; Nadalia & Pulunggono, 2020). In line with the results, Sembiring (2008) stated that soil fertility in former bauxite mining sites was extremely low.

Soil pH, moisture content, soil temperature, nutrient status, organic matter content, tillage systems, and vegetation types significantly influenced soil conditions. It was also reported that each microorganism thrived within specific pH ranges. For example, microorganisms associated with degraded vegetation prefered low-pH environments, hence increasing the pH can reduced its population and soil activity. Higher soil pH values were associated with greater species diversity, as reported by Salam (2020). According to Aprillia *et al.*, (2021), one of the factors responsible for lowering soil pH is the land composition, such as clay and sand, which possessed limited capacity to retain water. In addition to soil acidity, the organic matter content played a crucial role in increasing nutrient availability and improving soil fertility. Sembiring (2008), stated that the physical and chemical properties of soil in former bauxite mining areas were inferior compared to natural and plantation forests. The chemical properties of soil in these areas, particularly nitrogen (N) levels, were extremely low, with an average concentration of 0.09%, less than the amount required for plant growth. The soil pH ranged from 4.11 to 5.28, which is acidic but suitable for cultivating specific plant species to reduce acidity.

The amount of groundwater flowing into rivers from former bauxite mining areas was minimal. Observations carried out in the field showed that during the dry season, there were no springs near these sites (Sembiring, 2008). Hanafiah (2014) further reported that the organic matter levels influenced soil moisture content. As a result, the higher the organic matter content, the greater the soil's moisture retention. High organic matter content in bare land was evident from the abundance of decomposed leaf litter observed during field analyses. In this regards, the litters eventually forms the organic horizon in undisturbed soil layers.

Soil temperature affected water absorption, with lower temperatures resulting in reduced water uptake by plant roots, and sudden drops could lead to wilting. Meanwhile, soil temperature fluctuations depended on the depth of the soil layer (Lubis, 2007). Wehr *et al.,* (2006), stated that the water requirement for vegetation in bauxite residue disposal areas was greater than its availability in the soil layers. There is need to increase the soil layer thickness, improve the red mud, or implement irrigation to meet the water needs of the vegetation. The available water in the soil capping layer ranged from 130 to 220 mm. According to Martins *et al*., (2021), exploring the physical properties of Technosols, such as infiltration, water retention, and porosity, were considered promising areas for future research.

Chemical, physical, and variables interact to determine soil quality, with pH, and organic matter playing essential roles in enhancing soil fertility and sustainable land rehabilitation. Management systems that combine cover crops and fertilization positively impacted soil quality. However, intensive land use without protective measures degraded soil quality, including compromising organic matter stability (Cavalcante *et al.*, 2023).

Fourier Transform Infrared (FTIR) soil analysis showed that contents of clay and organic matter directly affected soil water retention ability due to the larger surface area. Sandy soils had large particles and pores that lacked reasonable ability to retain water, making it drain excessively. The clay content and organic matter directly affected the water retention capacity due to the larger surface area. As a result, smaller particle sizes, such as in clay soils, had larger surface area. The greater the surface area, the easier it is for the soil to retain water, thereby increasing the retention capacity (Gabor, 2023).

High clay soils were more effective in protecting carbon (C) and nitrogen (N) through complexation mechanisms, ensuring the stability of Mineral-Organic Matter (MOM) for fertility purposes. However, low clay soils were susceptible to losing organic matter (Carmo *et al*., 2012; Santos *et al*., 2011, 2013). Aprilia *et al*., (2021), stated that in respect to the physical properties, 50% of the soil comprised minerals and organic matter, while the remaining 50% consisted of pore space filled with water and air. In this regards, fertile soil should possess balanced quantity of sand, clay, and silt texture.

Water dispersion (spreading) in sandy loam soil types with a sand concentration of 70% is characterized by a low porosity value and rapid water conductivity. This process has a fairly good spread rate in sandy loam soil types due to its low porosity and large pores, resulting in exceptional aeration and rapid water conductivity (Tanga *et al*., 2020).

Certain plant populations were resistant to heavy metals, although these could grow on contaminated soils. The dominant strategy was to prevent metal absorption, temporarily limiting its transfer. Moreover, some species become altered or rare around mining sites. Peralta-Videa *et al*., (2009), stated that this led to the comparison between contaminated and uncontaminated environments. According to Solihat (2022), understory vegetation was often found in damaged habitats, resulting in the categorization as pioneer plant species in ex-mining sites. Erfandi (2017), reported that the following ground cover plants *Dolichos lablab, Crotalaria* sp., *Canavalia* sp., *Vigna* sp., *Tephrosia* sp., *Dioscroea* sp., *Ipomoea batatas*, *Mucuna* sp., *Arachis pintoi*, *Centrosema* sp., *Calopogonium* sp. Chauhan and C. S. Silori (2019), conducted a research on the success of bauxite residue reclamation through reforestation activities in South India. It was reported that in the first year, the average survival was approximately 80% among the five selected species, namely *Leucaena leucocephala*.

The selection of fast-growing plants with strong root systems was crucial for revegetation, with legume, grass, and rubber ground cover plants regarded as excellent choices. These plants improved soil fertility, reduced erosion, and increased the availability of nutrients required for plant growth (Aprillia *et al*., 2021). Ribeiro *et al*., (2019), reported that after monitoring bauxite mining in May 2015, the seedling planting area and natural regeneration produced 371 individuals from 106 species, and 171 individuals from 27 species, respectively. The seedling planting area had higher species diversity compared to natural regeneration. This was in line with the result of the current research, that only five species were found compared to the former bauxite mining site.

Plants successfully cultivated on former mining sites included cover crops for controlling erosion, fast-growing pioneer trees, late-stage local species for ecosystem restoration, and vegetation supporting biodiversity around pit lakes (Pratiwi *et al*., 2021). Rashtian *et al*., (2020), reported that bauxite mining damaged the soil, while having significant impacts on dominant vegetations, such as *Zygophyllum eurypterid*, found in the arid regions of Taft, Yazd Province.

Following the description above, the vegetation composition found in the Bauxite Residue Disposal Area (BRDA) in Central China was dominated by *Cynodon dactylon* and herbaceous species of the Mocho Mountains in Jamaica. At site CC24, the vegetation mainly consisted of African star grass (*Cynodon nlemfuensis*), fern, and tropical shrubs such as black sage (*Cordia curassavica*) and bamboo (*Bambusa vulgaris*) (Huang *et al*., (2022). Additionally, at sites F25 and C9, *Panicum maximum* and *Brachiaria* were found (Lewis *et al*., 2010). Plant species that could tolerate alkali and salt were used for the revegetation of bauxite residue in Gove. These included *Chloris gayana*, *Cynodon dactylon* (an exotic pasture grass), *Sporobolus virginicus* (native grass), *Stylosanthes humilis* (exotic pasture legume), *Acacia multisiliqua* (native shrub), *Acacia holosericea*, *Acacia leptocarpa*, *Eucalyptus alba*, *E. polycarpa*, *Melaleuca viridiflora*, and *Casuarina equisetifolia* (native trees). The natural vegetation found around the BRDA was dominated by various species of trees and plants, namely *Eucalyptus tetrodonta*, *Eucalyptus miniata*, *Acacia leptocarpa*, *Acacia aulacocarpa*, *Livistona humilis*, *Sterculia diversifolia*, *Brachychiton paradoxus*, and *Grevillea pteridifolia* (Wehr *et al*., 2006). *Croton matourensis* and *Vismia guianensis* (dominant species) from natural regeneration appeared at an early successional stage after bauxite mining. Simultaneously, the reference forest (R-forest/control) contained 122 species (Martins *et al*., 2021).

The natural weathering process and vegetation encroachment gradually reduce the alkalinity of bauxite residues, improving its suitability. Furthermore, the presence of vegetation and microorganisms played a crucial role in altering the chemical properties of bauxite residues, resulting in more environmentally friendly-native soil with thick grass cover (Huang *et al*., 2022).

Unmined bauxite soil exhibited higher and more balanced microbial functional diversity compared to rehabilitated sites. This showed the influence of long-term disturbances, and the need for ecosystem recovery. Moreover, unmined soils also contained higher biomass and microbial populations than rehabilitated sites (Lewis *et al*., 2010).

Based on several reviewed research, no species similarity was found among the results obtained from former bauxite mining sites. This showed that each former bauxite mining site hosted unique species, influenced by differences in post-mining habitat characteristics, the extent of land degradation, natural recovery processes, and ecological interactions within the region. The results outlined the importance of understanding biodiversity in former bauxite mining sites.

The abundance of species that make up the vegetation (flora) below the former bauxite mine

The highest value index of 51 found at the Dompak site was Species Poaceae as shown in table 1. Based on Table 2, the highest value index of 37.10 found at the Senggarang site was *P. cernua*. The highest value index of 70 found at not a former bauxite mine in Senggarang was *D. linearis* as shown in Table 3. These three plants were the most dominant found in the three sites. Meanwhile, the non-dominant plants found at the dompak site, were *C. filiformis*, *P. tremuloides*, and *V. blattaria*. *Grona triflora* and *G. tristis* were found at the senggarang site. The non-dominant plant found at a former bauxite mine site in Senggarang was *Cyperus aromaticus*.

Pteridophyta showed a unique life cycle, due to the combined impact of the wind-dispersed spores with free-living gametophytes (Sureshkumar *et al*., 2020). These unique characteristic features increased the level of complexity during the biogeographic comparisons of pteridophytes with other vascular plants (Watkins *et al*., 2006). Ferns do not produce seeds, fruits, or flowers, rather it reproduces through spores. The spores are produced through the division of mother cells in the sporangium (Tjitrosoepomo, 2012). Poaceae usually grows on both dry and wetlands, including virtually all open or protected tropical and subtropical areas (Tjitrosoepomo, 2012). However, non-dominant plants relied on vegetative distribution compared to Pteridophyta and Poaceae, which are widely spread.

The species importance index included all the parameters to determine the distribution pattern and frequency, including assessing the ecological conditions that are more significant in forest succession. Furthermore, a species' high Importance Index showed it was due to the presence of environmental factors that supported the growth and survival of fern (Seyed *et al*., 2012).

The importance index was used to identify ecologically significant species in a forest ecosystem, as well as assessing the role in ecosystem. The spatial distribution and dominance were influenced by both intrinsic characteristics and environmental factors. Species with high IVI were considered ecologically significant compared to those with low IVI. This index ranked species to determine significant elements of the Jello-Muktar dry afromontane forest trees, with variations observed between successional stages and sites (Reshad *et al.*, 2020). Parmadi *et al*., (2016) further reported that the differences in the IVI of mangrove vegetation was due to competition for nutrients and sunlight at the research site.

In the seedling planting area, the Fabaceae family had the highest IVI of 135.6%, outlining its significance in ecological restoration due to the nitrogen-fixing ability. The Hypericaceae family had the highest IVI in the natural regeneration area, despite consisting of only one species (Ribeiro *et al*., 2019). Seameo Biotrop (2013) stated that species with a high IVI grew and thrived in areas with high soil acidity due to the ability to adapt to such conditions.

Several native species in other forest ecosystems responded positively to gradual increase in light associated with catching invaders, compared to rapid increases related to clear-cutting. Although the resource supply levels could be manipulated to support the establishment of essential native forest species and minimize the establishment of invasive species, there may be some invaders that require direct control to successfully restore native-dominated forests (Loh *et al*., 2008). The identification of understory plants provided essential information for revegetation and ecosystem restoration strategies. These species were also expected to be used as pioneer plants for soil improvement, including initiating the process of broader ecosystem recovery.

Mining activities threatened biodiversity both directly and indirectly through habitat loss and broader environmental changes, respectively. However, certain opportunities conformed mining with conservation agendas through strategic planning, new technologies, and cross-sector collaboration (Sonter *et al.,* 2018). Katona *et al.,* (2023) reported that the standardization of sampling protocols and biodiversity definitions enhanced global comparisons. This allowed discussions and decisions regarding the inclusive nature and effectiveness of environmental management. Low biodiversity is not always detrimental, as each ecosystem evolved according to its conditions. Standardizing sampling and biodiversity definitions improved management and conservation activities.

Mining sites in Brazil were more biodiverse in terms of metrics and taxonomies, due to the emergence of species. Some were rich in angiosperm, arthropod endemism, and phylogenetic as a result of deforestation which greatly impacted various aspects of biodiversity. The loss of biodiversity could hinder the adaptation of ecological communities to environmental changes, threatening the survival of lineages that had adjusted to current conditions. This included the risk of losing unidentified aspects of biodiversity that may have future value (Lloyd *et al.,* 2023).

The similarity index between the two forests was high, with Sorensen greater than 50%, indicating rich and unique plant diversity in both areas. The value obtained led to the protection, sustainable management, and the establishment of buffer zones, essential for preserving ecosystems as well as preventing forest degradation (Christopher 2020). Sidabukke *et al*., (2022), observed a low similarity index at the research site, which was attributed to differences in environmental factors between the two locations, such as air humidity, temperature, sunlight intensity, and forest management practices.

CONCLUSIONS

The following conclusions were drawn based on the results and discussion above: Understory plants found in the three sites consisted of 17 families with 24 species. The IVI at each site included: at Dompak, Poaceae (51%), Senggarang, *Palhinhaea cernua* (37.10%), and the non-former bauxite mine site in Senggarang, *Dicranopteris linearis* (70.00%). The Sorensen similarity index values for the three locations had the following percentages: 46.7% for the Dompak and Senggarang sites, 41.7% for the Dompak and the non-former bauxite mining sites, and 50% for the Senggarang and the non-former bauxite mining sites. The results proved that invasive species, such as Poaceae and *Dicranopteris linearis*, played a critical role in natural recovery and should be prioritized in revegetation efforts. This research provided essential knowledge for rehabilitating degraded lands and understanding vegetation recovery patterns in ex-mining sites.

Acknowledgements
We want to thank the Gadjah Mada University, Doctor in Biology, Faculty of Biology, Indonesia Endowment Funds for Education (LPDP), Center for Higher Education Funding (BPPT), Head of the Tanjungpinang City Research and Development Development Planning Agency with letter number 071/40/4.5.01/2024, Head of the Tanjungpinang City One Stop Investment and Integrated Services Service, Head of Senggarang Village, Tanjungpinang City, Head of Dompak Village, Tanjungpinang City.

Funding. This research was partially financed by Indonesia Endowment Funds for Education (LPDP), Center for Higher Education Funding (BPPT), with letter number 02070/J5.2.3/BPI.06/9/2022.

Conflict of interest statement. The authors declare that they have no competing interests.

Compliance with ethical standards. This work is a systematic review, with no local ethical approval required.

Data availability. Availability of data and materials statement. At the request of the authors.

Author Contribution Statement (CRediT). Erda Muhartati: Conceptualization, methodology, validation, investigation, writing original draft preparation, review and editing, project administration., **Andhika P-Nugroho:**

methodology, validation, investigation, review and editing, data curation., **Diah Rachmawati:** methodology, validation, investigation, review and editing, data curation., **Purnomo:** Conceptualization, methodology, validation, investigation, review and editing, formal analysis, data curation. All authors have read and agreed to the published version of the manuscript.

REFERENCES

Allan, H.H., 1961. *Flora of New Zealand. Vol. I. Indigenous Tracheophyta: Psilopsida, Lycopsida, Filicopsida, Gymnospermae, Dicotyledones.* Government Printer, Wellington.

Aprillia, R., Mukhtar, W., Setiawati, S. and Asbanu, G.C., 2021. Karakteristik tanah bekas tambang bauksit dan tailing di Kabupaten Sanggau, Kalimantan Barat. *Jurnal Pendidikan Informatika dan Sains*, 10(2), 208-217. https://journal.ikippgriptk.ac.id/index.php/saintek.

Arana, M.D., Gonzalez, H.A., Bonifacino, M. and Brussa, C.A., 2017. A revision of Lycopodiaceae from Uruguay. *International Journal of Advanced Research in Botany, 3*(4), 24-39. https://doi.org/10.20431/2455-4316.0304004

Arisandi, R., Dharmono, and Muchyar., 2015. Keanekaragaman spesies familia Poaceae di kawasan reklamasi tambang batubara PT Adaro Indonesia Kabupaten Tabalong. *Seminar Nasional XII Pendidikan Biologi FKIP UNS 2015*, 733–739.

Arisandi, R., Soendjoto, M. . and Dharmono., 2019. Keanekaragaman familia Poaceae di kawasan rawa Desa Sungai Lumbah, Kabupaten Barito Kuala. *EnviroScienteae*, 15(3), 390-396.

Backer, C.A., and van den Brink, R.B., 1963-1968, *Flora of Java: Spermatophytes only*, Vol. 1, N.V.P. Noordhoff-Groningen-The Netherlands, p. 431.

Bekele, T., 2017. *Bioprospecting Potential of Waltheria indica L. for Access and Benefit Sharing*, Genetic Resources Access and Benefit Sharing Directorate. https://ebi.gov.et/wp-content/uploads/2022/02/Bioprospecting-Potential-of-Waltheria-indica-L..pdf (accessed 2024 August 04).

Bohari, M. and Wahidah, B.F., 2015. Identifikasi jenis-jenis Poaceae di Desa Samata Kabupaten Gowa Sulawesi Selatan. *Dalam Prosiding Seminar Nasional Mikrobiologi Kesehatan dan Lingkungan* (hlm. 101-105). Makassar: Jurusan Biologi, Fakultas Sains dan Teknologi, UIN Alauddin Makassar. ISBN 978-602-72245-0-6.

Brink, M., 2003. *Curculigo Gaertn.* In M. Brink & R. P. Escobin (Eds.), *Plant resources of South-East Asia No. 17: Fibre plants.* Backhuys Publisher. Available at: https://edepot.wur.nl/411316 (accessed 2024 July 28).

Brownsey, P.J. and Perrie, L.R., 2020. *Flora of New Zealand: Ferns and lycophytes – Lycopodiaceae (Fascicle 27).* Manaaki Whenua Press. Available at: https://doi.org/10.7931/kyrt-4p89.

Carmo, F.F., Figueiredo, F.F., Ramos, M.L.G., Vivaldi, L.J. and Araújo, L.G., 2012. Frações granulométricas da matéria orgânica em Latossolo sob plantio direto com gramíneas. *Bioscience Journal*, 28, 420-431. (accessed 2024 December 26).

Cavalcante, D. ., Silva, I R. da. and Oliveira, T.S. de., 2023. Soil quality indicators for monitoring the short-term effects of mined soil rehabilitation strategies for bauxite. *Revista Brasileira de Ciências do Solo*, 47, e0220126. Available at: https://doi.org/10.36783/18069657rbcs20220126 (accessed 2024 December 26).

Chauhan, S. and Silori, C.S., 2019. An evaluation of successful reclamation of bauxite residue through afforestation activities in South India. *International Journal of Agroforestry and Silviculture*, 7(1). Available at: www.internationalscholarsjournals.org.

Christopher, A.O., 2020. Comparative analyses of diversity and similarity indices of West Bank Forest and Block A Forest of the International Institute of Tropical Agriculture (IITA) Ibadan, Oyo State, Nigeria. *International Journal of Forestry Research*, 2020(4865845), 8 pages. Available at: https://doi.org/10.1155/2020/4865845.

Cleland, J.B., n.d. The dispersal of plants by birds. *The S.A. Ornithologist.* Available at: https://birdssa.asn.au/images/saopdfs/Volume20/1952V20P072.pdf (accessed 2024 August 04).

Cox, G.W., 1978. *Ecology.* Wm. C. Brown Company Publishers.

Da Silva, J.M.C., Uhl, C. and Murray, G., 1996.

Plant succession, landscape management, and the ecology of frugivorous birds in abandoned Amazonian pastures. *Conservation Biology*, 10, 491-503. Available at: https://doi.org/10.1046/j.1523-1739.1996.10020491.x.

de Lange, P.J., 2013. *Dicranopteris linearis fact sheet* (content continuously updated). New Zealand Plant Conservation Network. Retrieved August 4, 2024, from https://www.nzpcn.org.nz/flora/species/dicranopteris-linearis/ (accessed 2023 September 30).

Ellison, C.A. and Evans, H.C., 1992. Present status of the biological control of graminaceous weed *Rottboellia cochinchinensis.* In *Abstracts of the VIII International Symposium on Biological Control of Weeds* (p. 66). Canterbury: Lincoln University, New Zealand.

Erfandi, D., 2017. Pengelolaan lansekap lahan bekas tambang: Pemulihan lahan dengan pemanfaatan sumberdaya lokal (In-Situ). *Jurnal Sumberdaya Lahan*, 11(2), 55-66.

Ezcurra, E., 2020. Chapter 13. *Poaceae: The grass family*. University of California, Riverside. Available at: https://ezcurralab.ucr.edu/sites/default/files/2020-05/13_poaceae.pdf. (accessed 2025 March 04).

Feng, Y., Wang, Y., 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. Available at: https://doi.org/10.1016/j.earscirev.2019.02.015.

Fryxell, P.A., 2000. *Flora Mesoamericana*, Volume **3**(2), Malvaceae (pp. 1-162). *Flora Mesoamericana*. Retrieved December 29, 2012, from https://www.tropicos.org/docs/meso/malvaceae.pdf. (accessed 2025 March 12).

Gabor, D.H., 2023. Effects of soil textures, soil settlements, and soil water-holding capacity on landslides: An experimental study for science teachers. *Indonesian Society for Science Educator Journal of Science Learning*, 6(2), 222-235. Available at: https://doi.org/10.17509/jsl.v6i2.54618.

Hanafiah, K.A., 2014. *Dasar-dasar ilmu tanah.* Jakarta: Rajawali Press.

Hardjowigeno, S., 2010. *Ilmu Tanah.* Jakarta (ID): Akademika Pressindo.

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(1), 83-88. Available at: https://doi.org/10.13057/nusbiosci/n080115.

Huang, N., Wu, H., Zhu, F., Cheng, Q. and Shengguo, X., 2022. Natural vegetation encroachment improves nutritional conditions of bauxite residue disposal area. *Bulletin of Environmental Contamination and Toxicology*, 109, 135–141. Available at: https://doi.org/10.1007/s00128-022-03479-6.

iNaturalist. (n.d.). *Melastomataceae.* Retrieved from https://www.inaturalist.org/taxa/48889-Melastomataceae (accessed 2025 March 04).

Katona, S., Paulikas, D., Ali, S., Clarke, M., Ilves, E., Lovejoy, T.E., Madin, L.P. and Stone, G. S., 2023. Land and deep-sea mining: The challenges of comparing biodiversity impacts. *Biodiversity and Conservation*, 32(6), 1125–1164. Available at: https://doi.org/10.1007/s10531-023-02558-2.

Kartika, N. and Humaira, N., 2023. Identifikasi tumbuhan famili Malvaceae di Kawasan Cigagak, Cipadung, Kecamatan Cibiru. *Jurnal Riset Rumpun Ilmu Tanaman (JURRIT)*, 2(1), 80-87. Available at: https://doi.org/10.55606/jurrit.v2i1.1440.

Lee, J.-T., Chu, M.-Y., Lin, Y.-S., Kung, K.-N., Lin, W.-C. and Lee, M.-J., 2020. Root traits and biomechanical properties of three tropical pioneer tree species for forest restoration in landslide areas. *Forests*, 11(2), 1-17. Available at: https://doi.org/10.3390/f11020179.

Lewis, D.E., White, J.R., Wafula, D., Athar, R., Dickerson, T., Williams, H.N. and Chauhan, A., 2010. Soil functional diversity analysis of a bauxite-mined restoration chronosequence. *Soil Microbiology*, 59, 710-723. [CrossRef] [PubMed].

Lloyd, T.J., Oliveira, U., Soares-Filho, B.S., Fuller, R.A., Butt, N., Ascher, J.S., Barbosa, J.P. P. P., Batista, J.A.N.B., Brescovit, A.D., de Carvalho, C.J.B., De Marco, P., Ferro, V. G., Leite, F.S.F., Löwenberg-Neto, P., Paglia, A.P., Rezende, D.T. de, Santos, A. J., Silva, D.P., Vasconcelos, M.F. de. and

Sonter, L.J., 2023. Multiple facets of biodiversity are threatened by mining-induced land-use change in the Brazilian Amazon. *Diversity and Distributions*, 29(6), 1190-1204. Available at: https://doi.org/10.1111/ddi.13753.

Loh, R.K. and Daehler, C.C., 2008. Influence of woody invader control methods and seed availability on native and invasive species establishment in a Hawaiian forest. *Biological Invasions*, 10(6), 805-819. Available at: https://doi.org/10.1007/s10530-008-9237-y.

López-Vicente, M., Calvo-Seas, E., Álvarez, S. and Cerdà, A., 2020. Effectiveness of cover crops to reduce loss of soil organic matter in a rainfed vineyard. *Land*, 9(7), 1-16. Available at: https://doi.org/10.3390/land9070230.

Lubis, S.K., 2007. Aplikasi Suhu dan Aliran Panas Tanah. *Universitas Sumatera*. Medan: USU.

Martins, W.B.R., Schwartz, G., Ribeiro, S.S., Ferreira, G., Barbosa, R., Paula, M., Barbosa, V.M. and Oliveira, F. De-Assis., 2021. Ecosystem restoration after bauxite mining: Favorable indicators for technosols construction and soil management using liming and subsoiling. *New Forests*, 52, 971-994. Available at: https://doi.org/10.1007/s11056-021-09834-5.

Michelangeli, F.A., 2018. Guide to the genera of lianas and climbing plants in the Neotropics: Melastomataceae. Available at: https://naturalhistory.si.edu/sites/default/files/media/file/melastomataceae_0.pdf. (accessed 2025 March 13).

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

Nesom, G.L., 2022. Melastomataceae Jussieu (Melastome Family). In *Flora of North America* (Vol. 10). Available at: http://floranorthamerica.org/Melastomataceae.

Odum, E.P., 1997. *Fundamentals of Ecology* (3rd ed.). Saunders College Publishing.

Parmadi, E. H., Dewiyanti, I. and Karina, S., 2016. Indeks nilai penting vegetasi mangrove di kawasan Kuala Idi, Kabupaten Aceh Timur. *Jurnal Ilmiah Mahasiswa Kelautan dan Perikanan Unsyiah*, 1(1), 82-95.

Parrotta, J.A., Wildburger, C. and Mansourian, S., 2012. Understanding relationships between biodiversity, carbon, forests and people: The key to achieving REDD+ objectives. A global assessment report. Prepared by the Global Forest Expert Panel on Biodiversity, Forest Management, and REDD+. *IUFRO World Series* Vol. 31.

Patra, D.K., Acharya, S., Pradhan, C. and Patra, H.K., 2021. Poaceae plants as potential phytoremediators of heavy metals and eco-restoration in contaminated mining sites. *Environmental Technology & Innovation*, 21, 101293. https://doi.org/10.1016/j.eti.2020.101293.

Peralta-Videa, J., Lopez, M.L., Narayan, M., Saupe, G. and Gardea-Torresdey, J.L., 2009. The biochemistry of environmental heavy metal uptake by plants: Implications for the food chain. *The International Journal of Biochemistry & Cell Biology*, 41(8-9), 1665-1677. https://doi.org/10.1016/j.biocel.2009.03.005.

Polunin, N., 1994. *Pengantar Geografi Tumbuhan dan Beberapa Ilmu Serumpun*. Yogyakarta: Gajah Mada University Press.

Prach, K. and Pyšek, P., 2001. Spontaneous succession in restoration: An ecological approach. *Ecological Engineering*, 16(1), 1-12. https://doi.org/10.1016/S0925-8574(00)00127-3.

Pratiwi, B., Narendra, B.H., Siregar, C.A., Turjaman, M., Hidayat, A., Rachmat, H.H., Mulyanto, B., Suwardi, Iskandar, Maharani, R., Rayadin, Y., Prayudyaningsih, R., Yuwati, T.W., Prematuri, R. and Susilowati, A., 2021. Managing and reforesting degraded post-mining landscape in Indonesia: A review. *Land*, 10(6), 658. https://doi.org/10.3390/land10060658.

Purwanto, A., Utaya, S., Dwiyono, and Handoyo, B., 2019. *Konservasi Lahan Tambang Bauksit dengan Tanaman Unggul Lokal*. Muhammadiyah University Press.

Rashtian, A., Monemi, N., Jafari, S.H. and Azimzadeh, H.R., 2020. The effect of bauxite mining on soil and dominant plant pollution in arid rangelands of Taft in Yazd

Province. *Desert*, 25(1), 101-108. Retrieved from http://desert.ut.ac.ir.

Renner, S.S., 1993. Phylogeny and classification of the Melastomataceae and Memecylaceae. *Nordic Journal of Botany*, 13, 519-540. https://doi.org/10.1111/j.1756-1051.1993.tb00096.x.

Reshad, M., Muhammed, M. and Beyene, A., 2020. Distribution and importance value index of woody species under different successional stages at Jello-Muktar dry Afromontane forest, South-eastern Ethiopia. *American Journal of Agriculture and Forestry*, 8(1), 1-8. http://dx.doi.org/10.11648/j.ajaf.20200801.11.

Ribeiro, S.S., Oliveira, F. de A., Ferreira, G.C., Santos, D.E. and Cruz, D.C., 2019. Forest restoration evaluation through indicators in areas of bauxite mining. *Floresta e Ambiente*, 26(3), e20170812. https://doi.org/10.1590/2179-8087.081217.

Sádlo, J., Chytrý, M., Pergl, J. and Pyšek, P., 2018. Plant dispersal strategies: A new classification based on the multiple dispersal modes of individual species. *Preslia*, 90(1), 1-22. https://doi.org/10.23855/preslia.2018.001.

Salam, A.K., 2020. *Ilmu Tanah*. Global Madani Press. Bandar Lampung.

Santos, D.C., Pillon, C.N., Flores, C.A., Lima, C.L. R., Cardoso, E.M.C., Pereira, B.F. and Mangrich, A.S., 2011. Agregação e frações físicas da matéria orgânica de um Argissolo Vermelho sob sistemas de uso no bioma pampa. *Revista Brasileira de Ciências do Solo*, 35, 1735-1744. https://doi.org/10.1590/S0100-06832011000500028. (accessed 2024 December 26).

Santos, D.C., Farias, M.O., Lima, C.L.R., Kunde, R. J., Pillon, C.N. and Flores, C.A., 2013. Fracionamento químico e físico da matéria orgânica de um Argissolo Vermelho sob diferentes sistemas de uso. *Ciência Rural*, 43(4), 838-844. https://doi.org/10.1590/S0103-84782013005000037.

Seameo Biotrop (Southeast Asian Regional for Tropical Biology), 2013. Invasive Alien Species. http://kmtb.biotrop.org (accessed 2024 December 26).

Sefmaliza, R. and Chairul, 2022. Komposisi dan struktur vegetasi tumbuhan bawah habitat flora langka *Rafflesia arnoldii* R.Br. di Hutan Bukik Pinang Mancuang, Kamang Mudiak, Agam. *Jurnal Biologi Universitas Andalas*, 10(2), 42-46. https://doi.org/10.25077/jbioua.10.2.42-46.2022.

Sembiring, S., 2008. Sifat kimia dan fisik tanah pada areal bekas tambang bauksit di Pulau Bintan, Riau. *Info Hutan*, 5(2), 123-134.

Seyed, M.R., Assadollah, M., Rahmatollah, R. and Farrivar, N., 2012. The assessment of plant species importance value (SIV) in Beech (*Fagus orientalis*) forests of Iran. *International Research Journal of Applied and Basic Sciences*, 3(2), 433-439.

Sidabukke, S.H., Barus, T.A., Utomo, B., Delvian, and Aulin, F.R., 2022. Similarity analysis of understorey plant species in forest areas. *Journal of Sylva Indonesiana*, 5(2), 113-123. https://doi.org/10.32734/jsi.v5i02.7375.

Sittadewi, E.H., 2008. Identifikasi vegetasi di koridor Sungai Siak dan peranannya dalam penerapan metode bioengineering. *Jurnal Sains dan Teknologi Indonesia*, 10(2), 112–118.

Skog, J.E., 2001. Biogeography of Mesozoic leptosporangiate ferns related to extant ferns. *Brittonia*, 53(2), 236-269. https://doi.org/10.1007/BF02812701.

Soegianto, A., 1994. *Ekologi Kuantitatif: Metode Analisis Populasi dan Komunitas.* Surabaya: Usaha Nasional.

Solihat, R.F., 2022. Analisis vegetasi perintis lokal di lahan bekas tambang pasir Kecamatan Cimalaka Kabupaten Sumedang. *Jurnal Belantara*, 5(1), 34-44. https://doi.org/10.29303/jbl.v5i1.483.

Solikin., 2004. Jenis-jenis tumbuhan suku Poaceae di Kebun Raya Purwodadi. *Biodiversitas*, 5(1), 23-27. https://doi.org/10.13057/biodiv/d050105.

Sonter, L.J., Ali, S.H. and Watson, J.E.M., 2018. Mining and biodiversity: Key issues and research needs in conservation science. *Proceedings B, The Royal Society Publishing*, 285, 20181926. http://dx.doi.org/10.1098/rspb.2018.1926.

Steenis, C.G.G.J. Van., 1978. *Flora Malesiana.* Alphen: Sijthoffamp: Noordhoff International.

Steenis, C.G.G.J. Van., 2006. *Flora*. Jakarta:

Pradnya Paramita.

Sureshkumar, J., Ayyanar, M. and Silambarasan, R., 2020. Pteridophyte species richness along elevation gradients in Kolli Hills of the Eastern Ghats, India. *Journal of Asia-Pacific Biodiversity*, 13(1), 92-106. https://doi.org/10.1016/j.japb.2019.11.008.

Tang, Y., Gilbert, M.G. and Dorr, L.J. (n.d.). Malvaceae. pp. 264-298. Retrieved from http://flora.huh.harvard.edu/china/mss/volume12/malvaceae.pdf. (accessed 2025 March 13).

Tanga, K.K., Kusuma, M.N., Musarofa, & Refaldin, H., 2020. Proses filtrasi dan dispersi jenis tanah sandy loam pada pengolahan air sungai. *Prosiding Seminar Teknologi Kebumian dan Kelautan (SEMINTAN II)*, 2(1), Juli 2020. Institute Teknologi Adhi Tama Surabaya (ITATS). ISSN 2686-0651.

The Royal Botanic Gardens & Domain Trust. (n.d.). Malvaceae. *PlantNET - The Plant Information Network System of The Royal Botanic Gardens & Domain Trust.* Retrieved from https://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?lvl=fm&name=MALVACEAE&page=nswfl. (accessed 2025 March 13).

Tjitrosoepomo, G., 2009. *Dasar-dasar Taksonomi Tumbuhan (Taksonomi Umum).* Universitas Gadjah Mada Press.

Tjitrosoepomo, G., 2012. *Taksonomi Tumbuhan (Spermatophyta).* Universitas Gadjah Mada Press.

Van Andel, J. and Aronson, J., 2012. *Restoration ecology: The new frontier.* Wiley-Blackwell.

Watkins, J.E., Jr., Cardelús, C., Colwell, R.K. and Moran, R. C., 2006. Species richness and distribution of ferns along an elevational gradient in Costa Rica. *American Journal of Botany*, 93(1), 73-83. https://doi.org/10.3732/ajb.93.1.73.

Wehr, J.B., Fulton, I. and Menzies, N.W., 2006. Profile revegetation strategies for bauxite refinery residue: A case study of Alcan Gove in Northern Territory, Australia. *Environmental Management*, 37(3), 297-306. https://doi.org/10.1007/s00267-004-0385-2.

Wenny, D.G., 2001. Advantages of seed dispersal: A re-evaluation of directed dispersal. *Evolutionary Ecology Research*, 3(1), 51–74.

WFO., 2024. *Dicranopteris linearis (Burm.f.) Underw.* Retrieved from http://www.worldfloraonline.org/taxon/wfo-0001107285 (accessed 2024 August 04).

Wibowo, C., Mulyana, D. and Wildasari, W., 2020. Komposisi jenis tumbuhan bawah dan sifat tanah di lahan bekas tambang kapur dan silika PT Holcim Indonesia Tbk. *Jurnal Silvikultur Tropika*, 11(2), 82-88. https://doi.org/10.29244/j-siltrop.11.2.82-88.

Windusari, Y., Susanto, R.H., Dahlan, Z. and Susetyo, W., 2011. Asosiasi jenis pada komunitas vegetasi suksesi di kawasan pengendapan tailing tanggul ganda di pertambangan PTFI Papua. *Biota*, 16(2), 242-251. https://doi.org/10.24002/biota.v16i2.106.

Wulandari, D.Y., Sari, M.S. and Mahanal, S., 2017. Identifikasi tumbuhan suku Poaceae sebagai suplemen mata kuliah keanekaragaman tumbuhan. *Jurnal Pendidikan: Teori, Penelitian, dan Pengembangan*, 2(1), 97-104.

SUPPLEMENTARY MATERIAL

Table S1. Plant species that make up the understory vegetation of former bauxite mines.

No	Name				Site (D, S, T)
	Family	Species	Synonym	Local name	
1	Asphodelaceae	*Dianella ensifolia* (L.) Redoute	*Anthericum japonicum* Thunb., *Cordyline ensifolia* (L.) Planch., *Dianella albiflora* Hallier f.	Rumput siak-siak	D, T
2	Asteraceae	*Ageratum conyzoides* L.	*Ageratum album* Hort.Berol., *Ageratum arsenei* B.L.Rob. *Ageratum conyzoides* f. *album* (Willd.) B.L.Rob., 1913	Daun tombak, babandotan	D
3	Bonnetiaceae	*Ploiarium elegans* Korth.	*Archytaea elegans* (Korth.) Choisy, *Hypericum excelsum* W.Hunter, *Vismia alternifolia* Turcz.	Riang- Riang, Kayu Kuat	D
4	Cyperaceae	*Carex otrubae* Podp.	*Carex cuprina* Nendtv., *Carex lamprophysa* Sam., *Carex otrubae* (Podp.) J.Kern & Reichg.	Rumput rubah palsu (pseudo fox-sedge)	D, S, T
5		*Carex* L.	*Agistron* Raf. *Ammorrhiza* Ehrh.	Alang-alang (the pill sedge)	S, T
6		*Cyperus aromaticus* (Ridl.) Mattf. & Kük.	*Cyperus aromaticus* subsp. *brachyrhizomatosus* Kük., *Cyperus teres* (C.B.Clarke) Lye, *Kyllinga aromatica* Ridl.	Rumput teki-tekian, navua sedge	T
7		*Gahnia tristis* Nees	*Gahnia stricta* Boeckeler, *Gahnia wichurae* Boeckeler, *Mariscus tristis* (Nees) Kuntze	Rumput tristis (rumput busuk)	S
8		*Lepironia articulata* (Retz.) Domin	*Chondrachne articulata* (Retz.) R.Br., *Choricarpha aphylla* Boeckeler, *Lepironia articulata* subsp. *capitata* (F.Muell.) Domin	Purun danau	S
9	Dilleniaceae	*Doliocarpus multiflorus* Standl.	-	Suku simpur-simpuran	D
10	Fabaceae	*Grona triflora* (L.) H.Ohashi & K.Ohashi	*Aeschynomene triflora* (L.) Poir., *Desmodium albiflorum* Cordem., *Hedysarum biflorum* Willemet	Sisik betok, rumput jarem	S
11	Gleicheniaceae	*Dicranopteris linearis* (Burm.f.) Underw.	*Dicranopteris discolor* (Schrad.) Nakai, *Gleichenia linearis* (Burm.fil.) C.B.Clarke, *Polypodium lineare* Burm.fil.	Paku resam	D, S, T
12	Hypoxidaceae	*Curculigo capitulata* (Lour.) Kuntze	*Curculigo foliis-variegatis* Pynaert, *Leucoium capitulatum* *Molineria capitulata* (Lour.) Herb.	Rumput palem, Congkok, sukkit	S
13	Lauraceae	*Cassytha filiformis* L.	*Rumputris fasciculata* Raf., *Calodium cochinchinense* Lour., *Cassytha americana* Nees	Tali putri	D, S
14	Lycopodiaceae	*Palhinhaea cernua* (L.) Franco & Vasc.	*Lepidotis cernua* (L.) P.Beauv., *Lycopodiella cernua* (L.) Pic.Serm., *Palhinhaea capillacea* (Spring) Holub	Paku kawat	D, S
15	Malvaceae	*Commersonia bartramia* (L.) Merr.	*Byttneria caledonica* Turcz., *Commersonia echinata* J.R.Forst. & G.Forst., *Muntingia bartramia* L.	Andilau, durian tupai	D
16		*Waltheria indica* L.	*Melochia corchorifolia* Wall., *Waltheria americana* L., *Waltheria debilis* Bojer	Daun pagi mengantuk	D
17	Melastomataceae	*Melastoma malabathricum* L.	*Melastoma baumianum* Naudin, *Melastoma malabathricum* var. *javanum* Bakh.f., *Melastoma normale* var. *divergens* Craib	Senduduk	D, S, T
18	Nepenthaceae	*Nepenthes gracilis* Korth.	*Nepenthes angustifolia* Mast. *Nepenthes distillatoria* Jack	Kantong semar	D, S

No	Name				Site (D, S, T)
	Family	**Species**	**Synonym**	**Local name**	
19	Pentaphylacaceae	*Adinandra dumosa* Jack	*Adinandra cyrtopoda* Miq., *Ternstroemia dumosa* Wall.	Api-api, layau, palempang	D
20	Poaceae	*Digitaria* sp.	*Acicarpa* Raddi, *Digitaria* Heist. ex Fabr. in Enum. Meth., *Digitariella* De Winter	Rumput jari	S
21		Poaceae	Aegilopaceae, Agrostidaceae, Alopecuraceae	Rumput	D, S, T
22		*Rottboellia cochinchinensis* (Lour.) Clayton.	*Aegilops fluviatilis* Blanco, *Ophiuros appendiculatus* Steud., *Rottboellia arundinacea* Hochst.	Rumput brandjangan, rumput gatal	D
23	Salicaceae	*Populus tremuloides* Michx	*Populus atheniensis* Lodd., *Populus aurea* Tidestr., *Populus tremuloides* Tidestr.	Pohon hawar bergetar	D
24	Scrophulariaceae	*Verbascum blattaria* L.	*Blattaria vulgaris* Fourr., *Thapsus blattaria* (L.) Raf., *Verbascum blattaria* f. *blattaria*	Bunga mullein ngengat	D

Information: D= Dompak, S= Senggarang, T= not a former bauxite mine