Floresta Ambient., Rio de Janeiro, 2023; 30(3): e20230022
https://doi.org/10.1590/2179-8087-FLORAM-2023-0022
ISSN 2179-8087 (online)

ORIGINAL ARTICLE – Silviculture

Composition, Structure and Diversity of Vegetation on Asphalt Post-Mining Sites in Buton Island, Indonesia

Albasri Albasri[1]
Faisal Danu Tuheteru[1]
Husna Husna[1]
Sugeng Budiharta[2]
Edy Jamal Tuheteru[3]
Sri Mulyono[4]
Tedi Yunanto[5]
Veni Karlin[1]

[1]Universitas Halu Oleo, Faculty of Forestry and Environmental Science, Department of Forestry, Kendari, Indonesia.
[2]National Research and Innovation Agency (BRIN), Research Center for Ecology and Ethnobiology, Bogor, Indonesia.
[3]Universitas Trisakti, Faculty of Earth and Energy Technology, Department of Mining Engineering, Jakarta, Indonesia.
[4]PT. WIKA Bitumen, Sulawesi Tenggara, Indonesia.
[5]Ministry of Energy and Mineral Resources, Bandung Polytechnic of Energy and Mining, Bandung, Indonesia.

Abstract

Studies related to reclamation on asphalt post-mining land are lacking. This study aimed to analyze the diversity of vegetation on asphalt post-mining sites in Buton, Southeast Sulawesi Province, Indonesia. The study focused on the composition, structure and diversity of plants on asphalt post-mining sites with varying ages (0-20 years) and overburden conditions. In total, this study recorded 105 plant species belonging to 37 families with richness index of 0.33-6.30 (low-high), diversity index of 0.31-2.96 (low-medium), and evenness index of 0.28-0.94 (low-high). The highest number of plant species was observed on the 7-year-old overburden site (46 species), suggesting that post-mining age is not necessarily the determinant factor of vegetation condition. There was arrested succession on the post-mining site with no overburden, implying that management of overburden is essential. Our study recommends that active planting using species from Rubiaceae family can be applied for reclamation of degraded land on asphalt post-mining areas.

Keywords: Arrested succession, asphalt, passive restoration, Rubiaceae.

1. INTRODUCTION AND OBJECTIVES

Mining sector has significant contribution to the global and national economy. One mining commodity which has important role in the national development is natural asphalt. Natural asphalt in the form of asphalt rock has been used as an additive substance in the processed asphalt used in various infrastructure developments, including roads, bridges, stadiums and many more infrastructure forms (Su et al., 2022). Indonesia is among the countries with the largest reserves of natural asphalt in the world (Widhiyatna et al., 2007). In Indonesia, such reserves are located in Buton Island, Southeast Sulawesi Province with average natural asphalt content of 20% (Suaryana, 2016) and total deposit of Buton asphalt (called Asbuton) of 667 million tonnes. There are two granule types of Asbuton, namely Buton Granular Asphalt (BGA) dan Lawele Granular Asphalt (LGA). The exploration and extraction of natural asphalt in Buton Island have been conducted since a long time ago with total production in 2019 alone was 865,000 tonnes. Buton's asphalt reserves of 667 million tonnes are equivalent to 340 million tonnes of processed asphalt (Indonesia.go.id, 2022).

The extraction of asphalt rocks is mostly conducted using open-pit mining technique. This technique unavoidably causes negative impacts on the surrounding environment, including the clearing of above-ground vegetations, removal of topsoil and sub-soil, modification of landscape, and changes in hydrological system and micro-climates conditions (e.g., temperature, humidity and light intensity) (Monjezi et al., 2009). Therefore, post-mining reclamation is imposed to bring back the degraded land to a proper state or to returning to a useful landscape (Bradshaw, 1996). Reclamation of post-mining land is important since the United Nations, along with many international organizations, have pledged the period of 2021-2030 as the decade of ecological restoration as a strategy to preserve natural capital of the earth (FAO-UNEP, 2020).

Reclamation of post-mining land usually involves two steps. First, it is generally started by recovering the physical, chemical and biological soil properties through several management interventions, such as returning previously removed topsoil, subsoil and rock (often called overburden/OB), conditioning of physical and chemical properties (e.g., creating drainage, adding calcite and organic fertilizer), and spreading nitrogen-fixing ground cover plants (e.g., legumes) (Trimanto et al., 2021). Once the soil condition is improved, we can proceed to the second step, i.e., revegetation. Revegetation of post-mining land aims to regain vegetation cover and improve plant diversity which in turn can restore the ecological functions of the landscape, especially if the previous post-mining area is a forested area. Revegetation of post-mining land can be carried out in two approaches, i.e., active revegetation through planting and passive regeneration by letting the vegetation to undergo natural succession (Bandyopadhyay and Maiti, 2019).

There are a great number of studies on reclamation of post-mining areas. In a recent review, Martins et al. (2020) recorded around 700 scientific articles studying restoration and environmental monitoring in post-mining lands. Yet, among such studies, no research has been focused on the reclamation of asphalt post-mining areas. This is understandable since asphalt is not a common mining commodity due to its rare occurrence compared to coal, gold, iron and nickel (Erskine et al., 2018; Hapsari et al., 2020). This knowledge gap might hinder a more sustainable practice in asphalt mining to mitigate the adverse impacts of mining operation to the surrounding environment.

Therefore, this study aimed to investigate the vegetation on asphalt post-mining sites in Buton Island, Southeast Sulawesi Province, Indonesia. This study focused on the composition, structure and diversity plant species that grow on asphalt post-mining sites with varying ages and overburden conditions in two locations, i.e., Kabungka and Lawele. These study areas in Buton Island are unique and important since this island is located in Wallacea region with distinct faunistic and floristic diversity, yet this region is increasingly pressured by various threats, including mining (Cannon et al., 2007; Voigt et al., 2021). The results of this study are expected to enrich the understanding of vegetation ecology of reclaimed asphalt post-mining area with unique Wallacean diversity in Indonesia.

2. MATERIALS AND METHODS

2.1. Study period and area

This study was conducted in July 2022 in two locations having mining concession permit (Ijin Usaha Pertambangan/IUP), i.e., IUP Kabungka and IUP Lawele, managed by PT. WIKA Bitumen, Buton Island, Southeast Sulawesi Province, Indonesia (Figure 1).

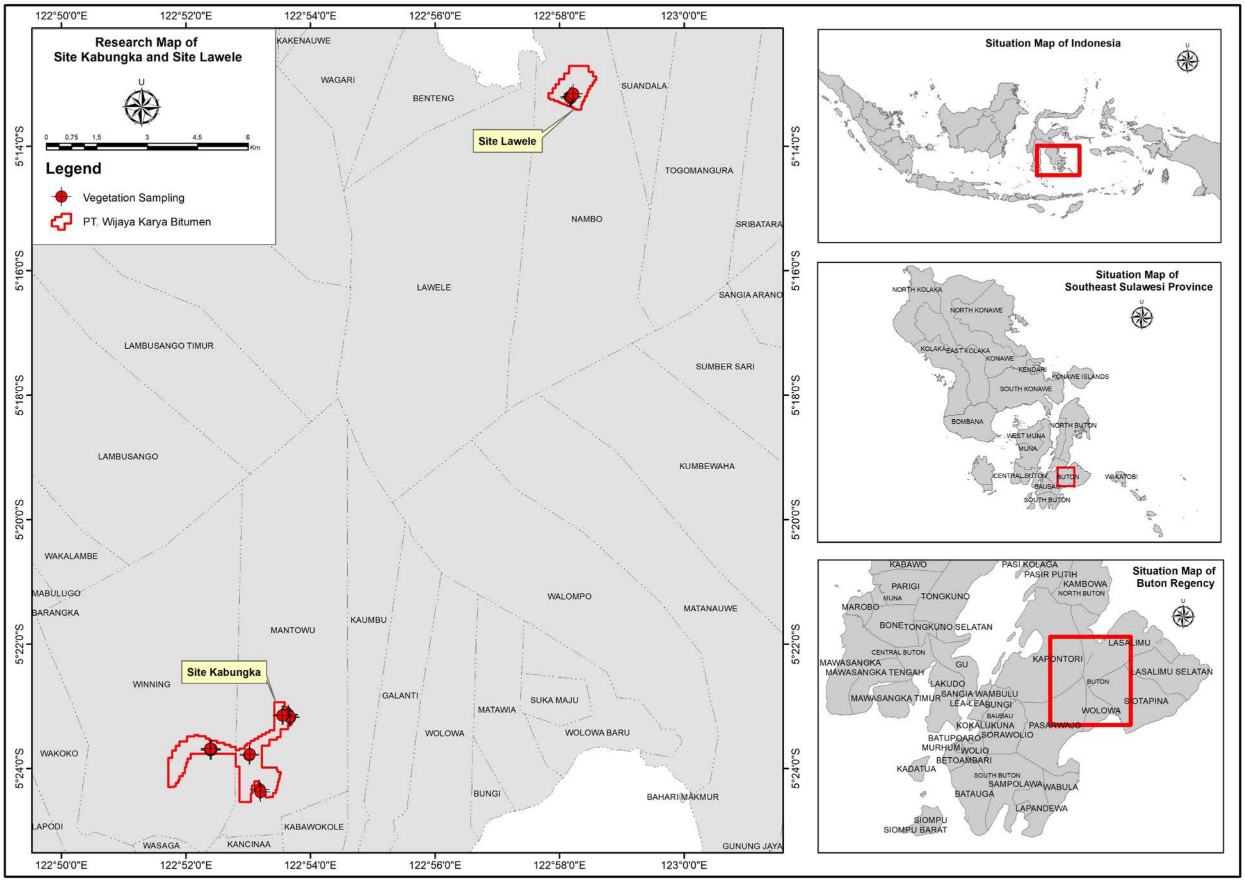

Figure 1. Map of study area showing the observation sites in two locations (i.e., IUP Kabungka and IUP Lawele) in Buton Island, Southeast Sulawesi Province, Indonesia.

2.2. Research design and data collection procedure

In the two research locations, we established observation sites representing various post-mining land ages and surrounding environmental conditions. The information regarding the ages of post-mining land was obtained from the company. At IUP Kabungka, there were six observation sites established on overburden sites with mining land age of 1 year (K1), 2 years (K2), 5 years (K5), 7 years (K7), 10 years (K10) and 20 years (K20). In IUP Lawele, there were two observation sites, namely a post-mining land with no overburden (LM10) and a 10-year-old overburden site (L10). In total, there were eight observation sites with their respective environmental conditions (Table 1). Climate data was obtained from River basin development agency region Sulawesi-IV, Kaisabu (IUP Kabungka) and Ngkaring Ngkaring station (IUP Lawele)

Table 1. Observation sites with varying mining land ages and the surrounding environmental conditions.

Site	Age (year)	Code	Geographical coordinates	Elevation (m asl)	Climate			
					Annual rainfall (mm)	Humidity (%)	Temperature (°C)	Radiation period
IUP Kabungka								
Site Winto	1	K1	122^0 53’ 38.76” 5^0 23’ 8.28”	153.99	2,340,19	96.60	29	36.95
	2	K2	122^0 53’ 40.44” 5^0 23’ 10.61”	159.21	2,340,19	96.60	29	36.95
	5	K5	122^0 53’ 33.96” 5^0 23’ 8.13”	163.77	2,340,19	96.60	29	36.95

Table 1. Continued...

Site	Age (year)	Code	Geographical coordinates	Elevation (m asl)	Climate			
					Annual rainfall (mm)	Humidity (%)	Temperature (°C)	Radiation period
IUP Kabungka								
Site C	7	K7	122^0 52' 23.48" 5^0 23' 42.14"	205.46	2,340,19	96.60	29	36.95
Site F	10	K10	122^0 53' 11.12" 5^0 24' 19.98"	173.78	2,340,19	96.60	29	36.95
Site E	20	K20	122^0 53' 1.17" 5^0 23' 46.97"	166.89	2,340,19	96.60	29	36.95
IUP Lawele								
OB	10	L10	122^0 58' 9.96" 5^0 13' 12.51"	35.24	2,076,48	98.73	29.67	27.97
Ex-mined site	10	LM10	122^0 58' 11.6" 5^0 13' 12.09"	41.32	2,076,48	98.73	29.67	27.97

2.2.1. Vegetation sampling

Sampling of vegetation was conducted purposively at the eight observation sites. Sample plot of 20 x 20 m was established to analyze the tree layers, and within each plot there were nested plots with size of 10 x 10 m, 5 x 5 m and 2 x 2 m to document pole, sapling and understory layer, respectively. At each observation site, 2-5 (tree, pole and sapling) and 10-25 (understory) sampling plots were established, resulting in total of 15 and 110 plots across the studied area. Ground cover plant, shrubs and tree seedling less than 1.5 m in height were considered as understories, while woody plant with more than 1.5 m in height and stem diameter less than 7 cm at breast height (dbh) was categorized as sapling. Woody plant with dbh between 10-19 cm was classified as pole, while woody plant with dbh of more than 20 cm was considered as tree. Within each plot, name of plant species, number of species and individual plant were recorded. Plant identification was conducted by taking the photographs of the plants to be identified by a botanist with experience of more than 30 years.

2.2.2. Soil sampling

Soil samples were taken from the rhizospheres in which one kilogram of soil sample from soil depth of 0-20 cm was taken from each plot. In total, there were 30 plots established for taking the soil samples. Each soil sample was kept in a plastic bag and coded with the name of each plot. The composite soil (± 1 kg) was sent to the Soil and Plant Laboratory of SEAMEO BIOTROP, Bogor, Indonesia for analysis. The chemical properties analysed included soil acidity (pH), C-organic using Walkey & Black method, N total using Kjeldahl method, C/N ratio, P2O5 using Bray method, Cation exchange capacity (CEC) and total metal element, while the physical properties included soil texture.

2.3. Data analysis

All plant species recorded in the observation sites were tabulated and calculated for the parameters of relative density (RD) based on their individual numbers per area, relative frequency (RF) based on their occurrences across plots, and relative dominance (RB) based on their basal area. The three parameters were then used to obtain the Importance Value Index (IVI).

Three biodiversity indicators were used, namely Shannon-Wiener diversity index-H' (Magurran 1988) with classification of H'<1 as low, 1≤H'≤3 as moderate, and H'>3 as high; Species Richness Index-R (Jørgensen et al., 2005) with classification of R<2.5 as low, 2.5≤R≤4 as medium, and R'>4 as high; and Evenness index-E (Magurran 1988) which can be categorized as unbalanced (0.00-0.25), less balanced (0.26-0.50), semi-balanced (0.51-0.75), almost balanced (0.76-0.95) and balanced (0.96-1.00).

3. RESULTS

3.1. Vegetation composition

In total, as many as 105 plant species from 39 families were recorded across the eight observation sites in IUP Kabungka and IUP Lawele, Buton Island (Table 2). Families with the largest number of species were Euphorbiaceae, Moraceae, Rubiaceae and Fabaceae. The number of plant species were different across sites with varying post-mining land ages. The 7-year-old overburden site in Kabungka (K7) had the highest number of plant species (46 plant species), followed by 34 species on the asphalt post-mining site with no overburden in Lawele

(LM10) and 26 species on the 2-year-old overburden site in Kabungka (K2). The lowest number of plant species (17 plant species) was recorded on the 10-year-old overburden site in Kabungka (K10). *Neolamarckia macrophylla* was the most common species recorded across all observation sites and across four vegetation layers (Table 2).

Table 2. Vegetation composition on asphalt post-mining sites with varying mining land ages and sites in Buton Island, Southeast Sulawesi Province, Indonesia.

No	Species	Family	Site							
			K1	K2	K5	K7	K10	K20	LM10	L10
1	*Aeschynomene indica* Wall.	Fabaceae	U							
2	*Ageratum conyzoides* L.	Asteraceae	U							
3	*Aleurites moluccanus* (L.) Willd.	Euphorbiaceae					U,T			
4	*Alocasia macrorrhizos* (L.) G.Don	Araceae				U				
5	*Alstonia spectabilis* R.Br.	Apocynaceae		U		U,S	S	U,S,T	U	U,S
6	*Alysicarpus vaginalis* (L.) DC	Fabaceae							U	
7	*Asystasia gangetica* (L.) T. Anderson	Acanthaceae							U	
8	*Amomum* sp.	Zingiberaceae	U		U	U		U		U
9	*Andropogon* sp.	Poaceae	U							
10	*Annona muricata* L.	Annonaceae					U			
11	*Ardisia elliptica* Thunb.	Primulaceae				U				
12	*Artocarpus elasticus* Reinw. ex Blume	Moraceae				U				
13	*Bidens biternata* (Lour.) Merr. & Sherff	Asteraceae				U				
14	*Blechnum finlaysonianum* Wall. ex Hook. & Grev.	Aspleniaceae	U	U	U,S	U		U	U	
15	*Blumea lacera* (Burm.f.) DC.	Asteraceae				U				
16	*Boehmeria* sp.	Urticaceae				S				
17	*Bombax ceiba* L.	Malvaceae				S				
18	*Borreria* sp.	Rubiaceae							U	
19	*Callicarpa candicans* (Burm.f.) Hochr.	Lamiaceae								
20	*Calopogonium mucunoides* Desv.	Fabaceae	U	U						
21	*Cananga odorata* (Lam.) Hook.f. & Thomson	Anonaceae								S
22	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Asteraceae	U	U	U	U	U		U	U
23	*Cyanthillium cinereum* (L.) H. Rob.	Asteraceae							U	
24	*Cyperus* sp.	Cyperaceae							U	
25	*Dendrocnide* sp.	Urticaceae	U							
26	*Desmodium* sp.	Fabaceae							U	
27	*Digitaria bicornis* (Lam.) Roem. & Schult.	Poaceae							U	
28	*Dillenia serrata* Thunb.	Dilleniaceae			U	U			U	
29	*Dioscorea pyrifolia* Kunth	Dioscoreaceae				U				
30	*Drynaria sparsisora* (Desv.) T. Moore	Polypodiaceae						U		
31	*Duabanga moluccana* Blume	Lythraceae			S					
32	*Eleutheranthera ruderalis* (Sw.) Sch.Bip.	Asteraceae	U							
33	*Emilia praetermissa* Milne-Redh.	Asteraceae		U						
34	*Erigeron* sp.	Asteraceae				U				
35	*Euphorbia heterophylla* L.	Euphorbiaceae							U	
36	*Euphorbia* sp1	Euphorbiaceae	U							
37	*Fibraurea tinctoria* Lour.	Menispermaceae				U				
38	*Ficus albipila* (Miq.) King	Moraceae				U				P
39	*Ficus ampelas* Burm.f.	Moraceae				U				
40	*Ficus fistulosa* Reinw. ex Blume	Moraceae				U,S				
41	*Ficus gul* Lauterb. & K.Schum.	Moraceae								U
42	*Ficus racemosa* Willd.	Moraceae							U	
43	*Ficus septica* Burm.f.	Moraceae	U	U	U	U,S			U	

Table 2. Continued...

No	Species	Family	Site							
			K1	K2	K5	K7	K10	K20	LM10	L10
44	*Ficus* sp 1	Moraceae	U	U,S	U,S,P	U,S,P		P		
45	*Ficus* sp 2	Moraceae			U,S,P	S			U	
46	*Ficus* sp 3	Moraceae		U						
47	*Ficus variegata* Blume	Moraceae				U,P		U,S		S
48	*Fimbristylis* sp.	Cyperaceae							U	
49	*Hemigraphis* sp.	Acanthaceae				U				
50	*Hyptis capitata* Jacq.	Lamiaceae		U	U				U	U
51	*Hypericum* sp.	Hypericaceae							U	
52	*Imperata cylindrica* (L.) P.Beauv.	Poaceae	U	U	U	U			U	
53	*Lantana camara* L.	Verbenaceae					U	U		U
54	*Leea indica* (Burm.f.) Merr.	Vitaceae								S
55	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae					U,S,P			
56	*Lygodium circinnatum* (Burm.f.) Sw.	Schizaeaceae		U						
57	*Macaranga gigantea* (Rchb.f. & Zoll.) Müll.Arg.	Euphorbiaceae			U			U,S,P		
58	*Macaranga involucrata* (Roxb.) Baill.	Euphorbiaceae				U,S				S
59	*Macaranga* sp 1	Euphorbiaceae		U,S	U	S		U,S		
60	*Macaranga* sp 2	Euphorbiaceae				S				S
61	*Macaranga* sp 3	Euphorbiaceae	U	U	S	U				
62	*Mallotus paniculatus* (Lam.) Müll.Arg.	Euphorbiaceae		U			U,S		U	U,S,P
63	*Mangifera* sp.	Anacardiaceae				U		S		U
64	*Melochia* sp.	Malvaceae							U	
65	*Merremia peltata* (L.) Merr.	Convolvulaceae			U					
66	*Microcos* sp.	Malvaceae						U,S,P,T		
67	*Mikania micrantha* Kunth	Asteraceae				U				
68	*Mikania* sp.	Asteraceae				U				
69	*Mimosa pudica* L.	Fabaceae		U					U	
70	*Muntingia calabura* L.	Muntingiaceae	U	U,S	U,S,P	S,P,T	S	S		
71	*Nauclea orientalis* (L.) L.	Rubiaceae		U		U			U,S	S,P,T
72	*Nauclea* sp.	Rubiaceae			S	U,S		S,P		
73	*Nauclea subdita* (Korth.) Steud.	Rubiaceae						U		
74	*Neolamarckia cadamba* (Roxb.) Bosser	Rubiaceae					T		U	P,T
75	*Neolamarckia macrophylla* (Roxb.) Bosser	Rubiaceae	U	U	S,P	U,S,P,T	U,P,T	U,S	U,S	S,T
76	*Neonauclea* sp.	Rubiaceae		U	U,S	U,S		S,T		
77	*Paspalum* sp.	Poaceae							U	
78	*Phyllanthus* sp 1.	Phyllanthaceae		U						
79	*Phyllanthus* sp 2.	Phyllanthaceae							U	
80	*Piper aduncum* L.	Piperaceae		U	U	U,S	U,S	S		
81	*Piper* sp.	Piperaceae						U		U
82	*Polyscias kjellbergii* (Philipson) Lowry & G.M.Plunkett	Araliaceae				S		U		
83	*Porophyllum ruderale* (Jacq.) Cass.	Asteraceae	U	U						
84	*Pouzolzia zeylanica* (L.) Benn.	Urticaceae							U	
85	*Psidium guajava* L.	Myrtaceae				U	S		U	U,S
86	*Pteris* sp.	Pteridaceae							U	
87	*Pteris tripartita* Sw.	Pteridaceae					U			
88	*Pteris vittata* L.	Pteridaceae		U					U	
89	*Pteris wallichiana* C.Agardh	Pteridaceae	U	U	U	U		U		
90	*Rubus moluccanus* L.	Rosaceae				U				
91	*Ruellia tuberosa* L.	Acanthaceae					U			
92	*Saraca* sp.	Fabaceae					U,S			
93	*Saurauia sp.*	Actinidiaceae				S				

Table 2. Continued...

No	Species	Family	Site							
			K1	K2	K5	K7	K10	K20	LM10	L10
94	*Senna obtusifolia* (L.) H.S.Irwin & Barneby	Fabaceae					U			
95	*Setaria* sp.	Poaceae	U	U	U				U	
96	*Spathoglottis plicata* Blume	Orchidaceae			U					
87	*Spathoglottis* sp.	Orchidaceae				U				
98	*Solanum torvum* Sw.	Solanaceae					U			U
99	*Spondias pinnata* (L.f.) Kurz	Anacardiaceae								T
100	*Stachytarpheta indica* (L.) Vahl	Verbenaceae	U	U		U				U
101	*Syzygium* sp.	Myrtaceae						U		
102	*Trema* sp.	Cannabaceae	U							
103	*Urena lobata* L.	Malvaceae								U
104	*Vitex cofassus* Reinw. ex Blume	Lamiaceae				U			U	U
105	*Unidentified 1*									U,S
	Total		**21**	**26**	**23**	**46**	**17**	**21**	**34**	**25**

Notes: K refers to observation sites in IUP Kabungka: i.e., overburden soils with mining land ages of 1 year (K1), 2 years (K2), 5 years (K5), 7 years (K7), 10 years (K10) and 20 years (K20). L refers to sites in IUP Lawele: i.e., post-mining land aged 10 years with no overburden soils (LM10) and 10-year-old overburden site (L10). Growth stages: U (understory), S (sapling), P (pole) and T (tree).

3.2. Vegetation structure

3.2.1. Tree layer

In total, there were eight species at tree stage, namely *Aleurites moluccanus*, *Microcos* sp., *Muntingia calabura, Nauclea orientalis, Neolamarckia cadamba, N. macrophylla, Neonauclea* sp., and *Spondias pinnata* (Table 2). Tree layer was only recorded on four sites, i.e., 7-year-old overburden site in Kabungka (K7), 10-year-old overburden site in Kabungka (K10), 20-year-old overburden site in Kabungka (K20), and 10-year-old overburden site in Lawele (L10). The L10 site had the highest number of plant species at the tree layer with four species, followed by K10 site with 3 plant species, and K7 and K20 sites with 2 plant species, respectively. Among the eight plant species at tree layer, 4 plant species belong to the family Rubiaceae, while Anacardiaceae, Euphorbiaceae, Malvaceae and Muntingaceae were represented by one species, respectively. *Neolamarckia macrophylla* had the highest Importance Value Index on the K7, K10 and L10 sites, while *Microcos* sp. was the most important species on K20 site (Figure 2).

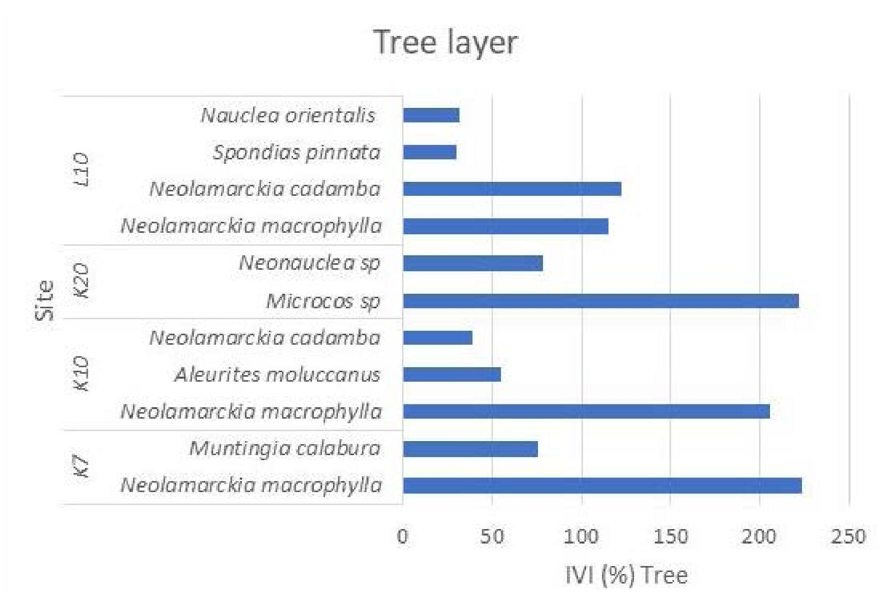

Figure 2. Important Value Index of tree layer across asphalt post-mining sites in Buton Island, Southeast Sulawesi Province, Indonesia.

3.2.2. Pole layer

There were 13 species at pole layer, namely *Ficus albipila*, *Ficus* sp 1, *Ficus* sp 2, *Ficus variegata, Leucaena leucocephala, Macaranga gigantea, Mallotus paniculatus, Microcos* sp., *Muntingia calabura, Nauclea orientalis, Nauclea* sp., *Neolamarckia cadamba* and *N. macrophylla* (Figure 3). Pole layer was only recorded on five sites i.e., 5-year-old overburden site in Kabungka (K5), 7-year-old overburden site in Kabungka (K7), 10-year-old overburden site in Kabungka (K10), 20-year-old overburden site in Kabungka (K20) and 10-year-old overburden site in Lawele (L10). The 20-year-old overburden site in Kabungka (K20) had the largest number of plant species at the pole layer with five species, followed by the K5, K7, and L10 sites with their respective four plant species, while the K10 site had two plant species. Rubiaceae and Moraceae showed the highest number of species at pole layer respective with four species, followed by Euphorbiaceae (2 species), and Fabaceae, Malvaceae and Muntingaceae with 1 species, respectively. *Neolamarckia macrophylla* had the highest IVI on the K5, K7 and K10 sites. At the L10 site, plant species having the highest IVI were two plant species, i.e *Neolamarckia cadamba* dan *Nauclea orientalis* of the family Rubiaceae, while on the K20 site, *Ficus* sp.1 had the highest IVI.

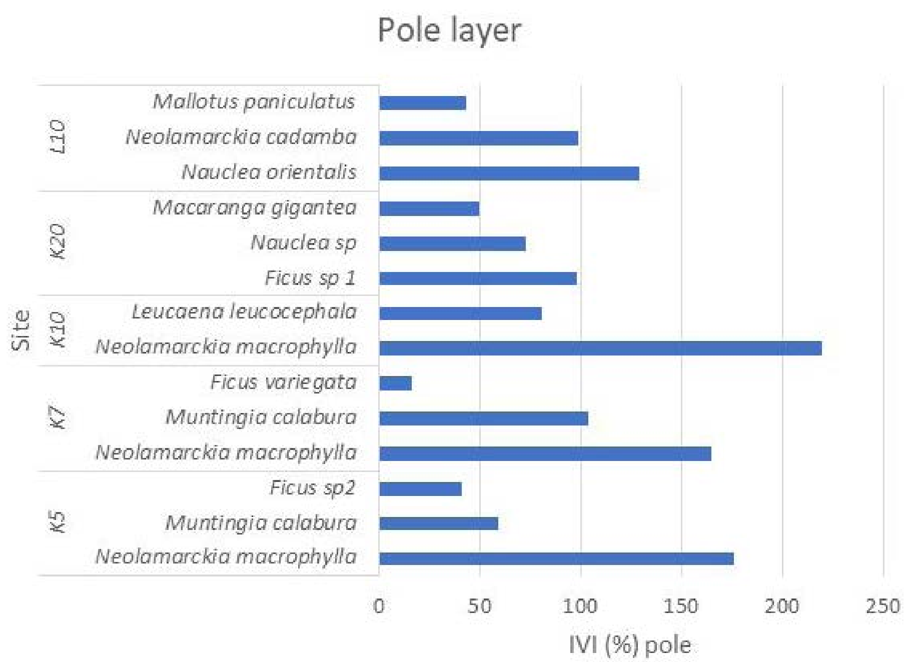

Figure 3. Important Value Index of pole layer across asphalt post-mining sites in Buton Island, Southeast Sulawesi Province, Indonesia.

3.2.3. Sapling layer

The sapling layer occurred on almost all observation sites, except on the 1-year-old overburden site in Kabungka (K1) (Table 2). In total, there were 31 species at the sapling level with three largest families were Rubiaceae and Euphorbiaceae (5 species each) and Moraceae (4 species). *Muntingia calabura* had the highest IVI on the K2, K5 and K7 sites (Figure 4). On the other hand, *Alstonia spectabilis, Leucaena leucocephala, Nauclea orientalis* and *Mallotus paniculatus* were the most important species on the K10, K20, LM10 and L10 sites, respectively. *Neolamarckia macrophylla* was among the three most important species on the K5, K7 and LM10 sites.

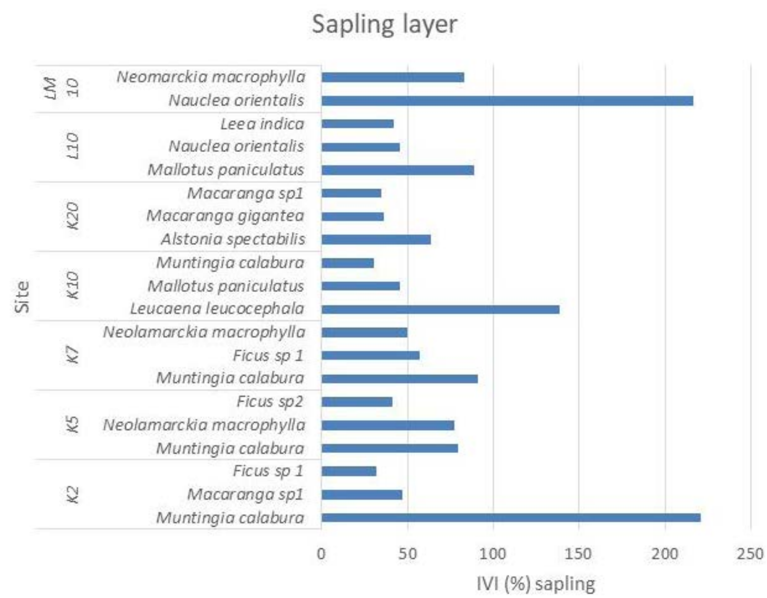

Figure 4. Three species with the highest Important Value Index of sapling layer across asphalt post-mining sites in Buton Island, Southeast Sulawesi Province, Indonesia.

3.2.4. Understory layer

The understory layer occurred on all observation sites with total of 98 species. The 7-year-old overburden site in Kabungka (K7) had the highest number of plant species at the understory layer, followed by the 10-year-old asphalt post-mining site in Lawele (LM10) with 34 species (Table 1). Five families with the largest number of plant species were Asteraceae (10 species), Moraceae (8 species), Fabaceae (7 species), Rubiaceae (6 species), and Euphorbiaceae (5 species). *Pteris wallichiana* had the highest IVI at the K1 and K7 sites which also occurred on the K5 and K20 sites (Figure 5). *Imperata cyindrica* was the most important understory species on the K2 site which also can be found on the K1 and LM10 sites. *Blechnum finlaysonianum* had the highest IVI on the K5 and K20 sites which were also recorded on the K1 and K7 sites. On the LM10 and L10 sites in Lawele, *Chromolaena odorata* had the highest IVI.

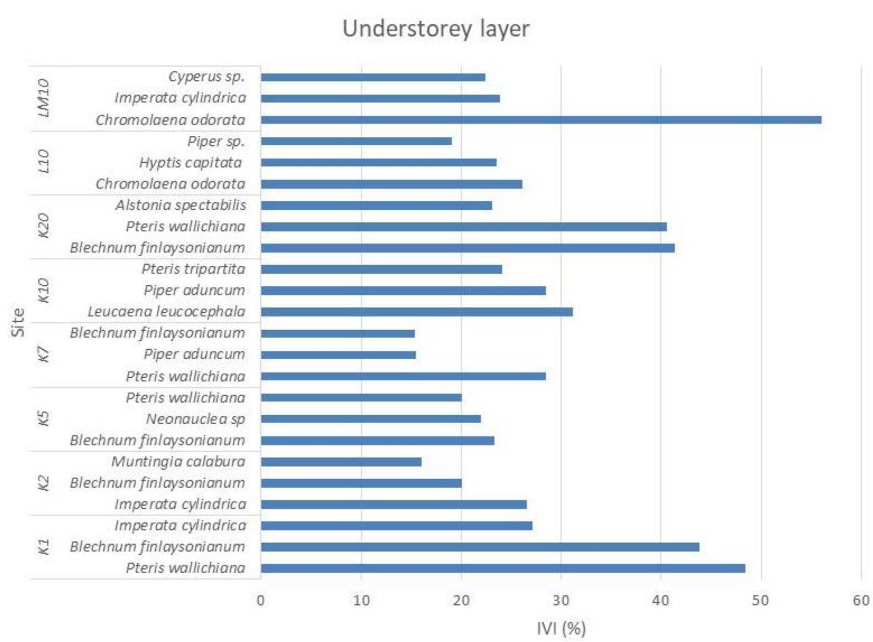

Figure 5. Three species with the highest Important Value Index at understory layer across asphalt post -mining sites in Buton Island, Southeast Sulawesi Province, Indonesia.

3.3. Diameter class distribution

Analysis of diameter class distribution at the sapling to tree levels showed that the vegetation in both of the former mining areas in the Kabungka IUP and Lawale IUP formed an inverted J-curve (Figure 6). This indicated that the vegetation on the asphalt post-mining sites resembles the structure of a non-aged stands. In general, the vegetation on the asphalt post-mining sites were dominated by small-diameter plants.

The relationship between diameter class and number of trees on the K2 site in the post-mining area in the Kabungka IUP and L10 site in the Lawale IUP had a high coefficient of determination (R2), namely R2 = 0.9256 for the K2 site and R2 = 0.9505 for the L10 site, respectively. Meanwhile, the area with the lowest coefficient of determination was on K10 in the Kabungka IUP with R2 = 0.3008. The high coefficient of determination indicated a close relationship between diameter class and number of trees, and vice versa.

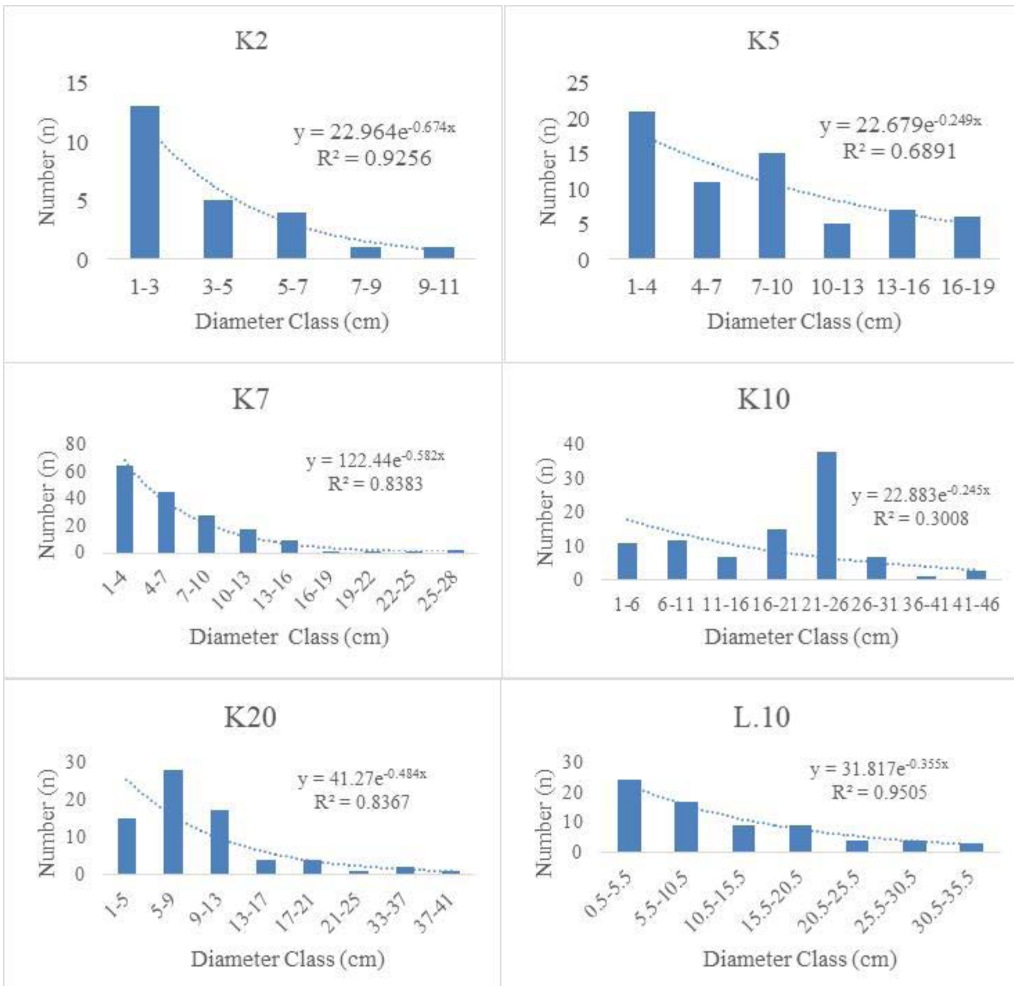

Figure 6. The pattern of diameter class distribution in the Kabungka IUP and Lawele IUP sites.

3.4. Biodiversity indicators

The results of analysis showed that Shannon-Wiener diversity index at tree and pole layers on the study sites where the two layers present (i.e. K7, K10, K20 and L10) was classified as low (Table 3). Low diversity index also occurred at the sapling layer across all observation sites, except on the K7 site which was categorized as moderate. On the other hand, across all observation sites, the diversity index for understory vegetation was classified as moderate, except on the K1 site which was classified as low.

The results of analysis on evenness index (E) indicated that the plant species were evenly distributed across all plots and layers, except for tree layer on the K10 site which had low evenness index due to high abundance of two species (i.e., *Neolamarckia macrophylla* and *Leucaena leucocephala*) with 675 individuals per hectare (Table 3, Figure 3). On other sites having tree stage (i.e., K7, K20 and L10 sites), there were only 20-150 individuals per hectare although they had higher number of plant species compared to the K10 site.

High richness index (R) for understory level was recorded on the K7 site with a value of 6.30, followed by the LM10 and K1 sites with values of 5.70 and 4.13, respectively, while other sites had moderate category. For sapling stage, the richness index across sites was classified as moderate, except on the K7, K20 and L10 sites which had high richness index. For tree and pole layers, the richness index was categorized as low in all sites (Table 3).

Table 3. Diversity index (H'), evenness index (E), richness index (R), species richness (number of species) and vegetation density on the observation sites in asphalt post-mining sites in Buton Island, Southeast Sulawesi Province, Indonesia.

Growth stage	Biodiversity indicator	Kabungka						Lawele	
		K1	K2	K5	K7	K10	K20	LM10	L10
Tree	Diversity Index (H')	-	-	-	0.56	0.31	0.50	-	1.14
	Evenness Index (E)	-	-	-	0.81	0.28	0.72	-	0.83
	Richness Index (R)	-	-	-	0.72	0.50	0.62	-	1.21
	Species richness	-	-	-	2	3	2	-	4
	Density (ind. ha^{-1})	-	-	-	20	675	63	-	150
Pole	Diversity Index (H')	-	-	0.88	0.95	0.50	1.51	-	1.23
	Evenness Index (E)	-	-	0.64	0.68	0.72	0.94	-	0.89
	Richness Index (R)	-	-	1.04	0.90	0.33	1.38	-	1.06
	Species richnessnumber	-	-	4	4	2	5	-	4
	Density (ind. ha^{-1})	-	-	900	560	1,000	900	-	850
Sapling	Diversity Index (H')	-	0.62	1.80	2.07	1.37	2.16	0.56	1.89
	Evenness Index (E)	-	0.56	0.82	0.72	0.70	0.90	0.81	0.79
	Richness Index (R)	-	0.63	2.08	3.45	2.00	2.57	0.72	2.69
	Species richness	-	3	9	18	7	11	2	11
	Density (ind. ha^{-1})	-	4,800	9,400	11,040	4,000	9,800	320	8,200
Understory	Diversity Index (H')	1.74	2.87	2.51	2.96	2.22	2.08	2.34	2.52
	Evenness Index (E)	0.57	0.85	0.87	0.82	0.87	0.77	0.66	0.91
	Richness Index (R)	3.12	4.13	2.79	6.30	2.30	2.34	5.70	2.96
	Species richness	21	26	18	37	13	15	34	16
	Density (ind. ha^{-1})	152,750	105,750	110,000	30,400	92,000	100,250	32,600	31,600

3.5. Soil properties

The chemical and physical properties of the soil samples are presented in Table 4. The soil pH was slightly alkaline (7.7 - 8.1). The P_2O_5 levels and CEC were categorized as very high in the Lawele IUP (L10 and LM10 sites). Both parameters are commonly used as indicators of soil fertility although they will interact with other soil properties such as soil pH to be optimal. Mg level was in the moderate category at the LM10 site. Soil texture was classified as loam at the K1, K2 and K5 sites and clay loam on the other sites.

Table 4. Soil chemical and physical properties on the observation sites in asphalt post-mining sites in Buton Island, Southeast Sulawesi Province, Indonesia.

Parameter	Unit	Kabungka						Lawele		Criteria
		K1	K2	K5	K7	K10	K20	L10	LM10	
pH H_2O (SNI 03-6787-2002)		8.1	8.1	8	7.9	7.7	7.8	7.8	7.8	All sites = slightly alkaline
C-organic (SNI 13-47211-1998 (Walkey & Black))	%	1.11	1.1	1.38	2.07	2.83	3.93	4.2	3.19	K1,K2,K5 = low; K7-K10 = moderate; K20,L10,LM10 = high
N Total (SNI 13-4721-1998 (Kjeldahl))	%	0.08	0.11	0.11	0.13	0.25	0.33	0.35	0.23	K1=very low; K2,K5,K7 = low; K10,K20,LM10,L10 = moderate
C/N ratio		14	10	13	16	11	12	12	14	K2=low; K1, K5, K10, K20,L10, M10=moderate; K7=high
P_2O_5 (SL-MU-TT-05 (Bray I/II)	mg/kg	1.92	1.37	1.63	3.3	9.46	10.3	16.6	19	K1,K2,K5,K7=very low; K10,K20=moderate; L10,LM10=very high
Cation exchange capacity/CEC (SL-MU-TT-07)										
Ca	cmol/kg	34.64	34.52	27.25	33.78	36.8	41.83	47.59	49.9	All sites = very high
Mg	cmol/kg	0.6	0,16	0.6	0.59	0.59	0.59	0,65	1.12	K2,K5=very low, K1,K7,K10,K20,L10=low, LM10=moderate
Na	cmol/kg	0.53	0.48	0.62	0.6	0.78	0.64	0.02	0.52	L10=very low, other sites = moderate
K	cmol/kg	0.16	0.64	0.3	0.2	0.48	0.49	1.14	1.49	K1, K5,K7 = low, K10,K20 = moderate, K2=high, L10, LM10 = very high
CEC	cmol/kg	9.04	8.88	7.11	10.61	16.32	15.81	27.62	25.16	K1,K2,K5,K7,K10,K20=low. L10,LM10=high
Texture SL-MU-TT-10 (Hydrometer)										
Sand	%	41	37.5	44	42.8	40.8	42.3	24.2	42.9	K1,K2,K5 = loam and other site = clay loam
Silt	%	20.4	23.9	20.7	31.1	29.6	34.6	26.7	34.3	
Clay	%	38.6	38.6	35.3	26.1	29.6	23.1	49.1	22.8	
Total metal element (HNO3-HclO4)										
Cu	ppm	11.2	11.3	10	10.4	11.8	8.12	16.6	15.1	normal
Zn	ppm	83.2	78.6	39.4	87.2	106	84.3	43.7	46.5	normal
Fe	%	0.43	0.45	0.42	0.52	0.54	0.42	0.6	0.58	
Mn	ppm	350	471	267	421	437	251	610	554	normal

4. DISCUSSION

In this study, Euphorbiaceae, Moraceae, Rubiaceae and Fabaceae were the plant families with the largest number of species on the asphalt post-mining land in Buton Island. The dominance of such families is likely influenced by the intrinsic factors of the plants, including the high adaption ability, the large number of seedlings produced and the characteristics of the fruits or seeds which are dispersed by wind and animals, particularly birds and bats. Within the Euphorbiaceae family, there were five species of *Macaranga* recorded on the overburden sites which are known as pioneer and fast-growing species.

Aleurites moluccanus, *Microcos* sp., *Muntingia calabura*, and *Neonauclea* sp., were found on the overburden sites in Kabungka IUP, while *Nauclea orientalis*, *Neolamarckia cadamba*, *N. macrophylla*, and *Spondias pinnata* were recorded on the overburden and the post-mining sites in Lawele IUP. The eight tree species found in this study are recommended for the revegetation of asphalt post-mining areas in Buton Island. *N. macrophylla* occurred across all observation sites at all growth stages. This species can grow on lowland forest (0-700 m asl), including on degraded areas, such as post-mining sites, on various soil types (i.e., ultisol, alfisol, oxisol, andosol, inceptisol and spodosol), with temperature range of 22-27°C and annual rainfall of 1,500(-2,000)-2,500 mm

(Tuheteru et al. 2019). Along with its high adaptation ability to various environmental conditions, the fruits and seeds of *N. macrophylla* are easily dispersed by animals (e.g., bats) and human. This species also has original distribution in lowland forest of Sulawesi (Whitten et al. 1987), thus *N. macrophylla* is considered as native plant species to the region. The presence of *N. orientalis* on the overburden and the post-mining sites in Lawele IUP is interesting for further study since this species is reported to occur on various ecosystems, including wetlands, savanna, karst and dryland (Tuheteru et al. 2014; 2015; 2016).

Despite the comparably older succession age, there were no vegetation at the pole and tree stages recorded on the post-mining site in Lawele IUP aged 10 years with no overburden (LM10). This result suggested that there was arrested succession on the LM10 site. The state of arrested succession is strengthened by fact that there was a high number of species at the understory layer which several of them are considered as invasive species (Table 2). Arrested succession can be defined as the hindrance of vegetation recovery from lower layer and juvenile stages (i.e., understory and saplings) into higher layers (i.e., poles and trees) caused by the reduction of ecosystem functions and processes (Soto et al., 2019).

Pteris wallichiana is an understory plant from family Pteridaceae which can be found on all studied sites. The dominance of this species is likely caused by the characteristic of its spore and sporangium which are easily dispersed by wind and the high adaptability on the soil having pH above 7. This species is reported to occur on tin mining wasteland in Gejiu City, Yunnan, China which had pH of above 7,5 (Xiang-bin et al. 2015). Besides *P. wallichiana*, *Blechnum finlaysonianum* from family Pteridaceae was also the dominant species on the overburden sites in Kabungka IUP. The grass *Imperata cylindrica* is widely distributed across tropical and sub-tropical regions and is considered as one of the most destructive invasive plant species (Rusdy 2020). The invasiveness of this grass is related to the thick and dense rhizome, allelopathy, the high reproduction rate by seeds and rhizome, high phenotypic plasticity and high adaptability on various environmental conditions, such as shading, drought and low soil fertility (Estrada and Flory, 2015). *Chromolaena odorata* was the dominant species on the overburden site (L10) and the post-mining site with no overburden (LM10) in Lawele IUP. Similar with *I. cylindrica*, *C. odorata* is among the most destructive invasive plants and noxious weeds which has high tolerance to broad range of environmental conditions. *C. odorata* is a considered fast-growing plant because its propagules are produced from generative dan vegetative organs and its small size of seeds are easily dispersed by winds. Several studies also reported that *C. odorata* dominated the understory vegetation on coal (Wiryono and Siahaan, 2013; Novianti et al. 2017; Hapsari et al. 2020), nickel (Purnomo et al. 2022) and gold (Albasri et al. 2021, Tuheteru et al. 2021) post-mining sites. Asteraceae is reported to be the most dominant family in coal post-mining sites (Wiryono and Siahaan, 2013; Novianti et al. 2017).

Based on the pattern of diameter class distribution of vegetation in both the Kabungka IUP and Lawele IUP study sites, all post-mining areas formed an L-shaped curve or an inverted J-shape. Astriyani and Pambudhi (2010) stated that the normal stand structure follows an inverted J-curve pattern, where the population of stands with smaller dimensions (small diameter) is denser (trees/ha) than those with large diameters. According to de Liocort's law, a natural forest stand is considered to be normal if its curve forms an inverted J. The distribution of diameter classes in a stand that forms an inverted J-curve is an indicator of a stable and growing stand. The stands have more trees in smaller classes, indicating continuous recruitment for natural succession (Gonçalves et al., 2017; Staporn et al., 2022). Therefore, it can be said that the post-mining areas in the two IUPs can accommodate the natural regeneration process with a level of diversity that ranges from low to moderate.

The soil pH was slightly alkaline (7.7 - 8.1) which is likely caused by the exposed asphalt deposits within the geological formation of limestone in Kabungka and Lawele IUPs which have high composition of CaCO3 with 72.90 dan 86.66% content, respectively (Siswosoebrotho et al. 2005). This is strengthened by the result of analysis which showed very high content of Ca in all observation sites (Tabel 4). The C-organic and total N tended to increase along with the increasing age of overburden and post-mining sites which is presumably caused by the input of litter as vegetation succession proceeded. Soil organic carbon is highly important for soil microbes as energy source, whereas N serves as macronutrient required by vegetation.

5. CONCLUSIONS

In conclusion, vegetation on asphalt post-mining sites in Buton Island, Southeast Sulawesi Province, Indonesia had low to moderate biodiversity even after 20 years of succession process, except for understory vegetation which had high biodiversity. The composition, structure and diversity of vegetation did not necessarily align with the age of post-mining land since the 7-year-old overburden site (K7) had comparably higher biodiversity indicators at all stages compared to the older sites (i.e., K10, K20, and LM10). Despite the high number of species documented (135 species from 39 families), only few number of species were at the pole and tree stages with only 8 and 13 species, respectively, which only occurred on the overburden sites with age of seven years and above (K7, K10, K20 and L10). The absence of vegetation at the pole and tree stages on the post-mining site with no overburden (LM10) indicated that the vegetation experienced arrested succession even after ten years. Such findings suggested that passive restoration is not sufficient to recover the vegetation in asphalt post-mining sites in Buton Island. Instead, active restoration is necessary to accelerate vegetation recovery. Also, letting the post-mining site to proceed natural regeneration without adding topsoil on the overburden site could lead to the vegetation recovery to be hampered. Therefore, we recommend that the management of overburden soil is essential in asphalt post-mining reclamation followed by active restoration by planting several native tree species from Rubiaceae family (*Neolamarckia macrophylla*, *N. cadamba* and *Nauclea orientalis*) to accelerate the vegetation recovery, enhance the biodiversity and suppress invasive alien species in the reclamation of asphalt post-mining land in Buton Island, Southeast Sulawesi Province, Indonesia.

ACKNOWLEDGEMENTS

The authors wish to thank the Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research and Technology of the Republic of Indonesia (No. 28/UN29.20/PG/2022 and 35/UN29.20/PG/2023). The authors would also like to thank the Director, Head of Mining Engineering and the staff of PT. WIKA Bitumen, Buton, Southeast Sulawesi Province, for the permission for research.

SUBMISSION STATUS

Received: 16 Jun. 2023
Accepted: 15 Aug. 2023
Associate editor: Bárbara Bomfim Fernandes:

CORRESPONDENCE TO

Faisal Danu Tuheteru
Anduonohu, Kec. Kambu, Kendari, 93232, Sulawesi Tenggara, Indonesia.
e-mail: faisal.danu.tuheteru_fhut@uho.ac.id

AUTHORS' CONTRIBUTIONS

Albasri Albasri: Conceptualization (Equal); Data curation (Equal); Formal analysis (Equal); Investigation (Equal); Methodology (Equal); Validation (Equal); Writing – original draft (Equal); Writing – review & editing (Equal).
Faisal Danu Tuheteru: Conceptualization (Equal); Data curation Supporting, Investigation (Supporting); Methodology (Equal); Project administration (Equal); Validation (Supporting); Writing – review & editing (Equal).
Husna Husna: Conceptualization (Equal); Data curation (Equal); Formal analysis (Equal); Investigation (Equal); Methodology (Equal); Validation (Equal); Writing – original draft (Equal); Writing – review & editing (Equal).
Sugeng Budiharta: Conceptualization (Equal), Investigation (Equal), Supervision (Equal), Writing – original draft (Equal), Writing – review & editing (Equal).
Edy Jamal Tuheteru: Data curation (Equal); Formal analysis (Equal); Methodology (Equal); Validation (Equal); Writing – original draft (Equal); Writing – review & editing (Equal).
Sri Mulyono: Project administration (Equal); Writing – original draft (Equal); Writing – review & editing (Equal).
Tedi Yunanto: Data curation (Equal); Formal analysis (Equal); Methodology (Equal); Software (Supporting); Supervision (Equal); Writing – review & editing (Equal).
Veni Karlin: Data curation (Supporting); Investigation (Supporting); Writing – original draft (Equal); Writing – review & editing (Equal).

FINANCIAL SUPPORT

The Directorate General of Higher Education, Research, and Technology, Ministry of Education, Culture, Research and Technology of the Republic of Indonesia (No. 28/UN29.20/PG/2022 and 35/UN29.20/PG/2023).

REFERENCES

Albasri, Tuheteru FD, Husna, Arif A, Basrudin, Azimudin, Berlian, Erif LOM. Vegetation composition in the community gold post-mining land and PT Panca Logam Nusantara in Bombana Regency, Southeast Sulawesi Province. IOP Conf. Ser.: Earth Environ. Sci. 800 012046; 2021. https://doi.org/10.1088/1755-1315/800/1/012046

Astriyani, Pambudhi F. Analisis Bentuk Struktur dan Hubungannya Dengan Riap Tegakan Tunggal Hutan Alami Produksi. Jurnal Kehutanan Tropika Humida 2010; 3 (1): 28-41.

Bandyopadhyay S, Maiti SK. Evaluation of ecological restoration success in mining-degraded lands. Environ Qual Manage. 2019; 1–12. https://doi.org/10.1002/tqem.21641

Bradshaw A. Underlying principles of restoration. Canadian Journal of Fisheries and Aquatic Sciences, 53(S1), 7. 1996. https://doi.org/https://doi.org/10.1139/cjfas-53-S1-3

Cannon CH, Summers M, Harting JR, Kessler PJA. Developing Conservation Priorities Based on Forest Type, Condition, and Threats in a Poorly Known Ecoregion: Sulawesi, Indonesia. Biotropica 2007; 39, 747-759. https://doi.org/10.1111/j.1744-7429.2007.00323.x

Erskine PD, Lee G, Fogliani B, L'Huillier L, McCoy S. Incorporating Hyperaccumulator Plants into Mine Rehabilitation in the Asia-Pacific Region. in Van Der Ent A, Echevarria G, Baker AJM, Morel JL (Editors) : Agromining: Farming for Metals: Extracting Unconventional Resources Using Plants. Springer International Publishing, Cham; 2018.

Estrada JA, Flory SL. 2015. Cogongrass (*Imperata cylindrica*) invasions in the US: Mechanisms, impacts, and threats to biodiversity. Global Ecology and Conservation 2015; Volume 3, January 2015, Pages 1-10

FAO-UNEP. 2020. State of The World Forest 2020. FAO, Roma

Gonçalves FMP, Revermann R, Gomes AL, Aidar MPM, Finckh M, Juergens N. 2017. Tree Species Diversity and Composition of Miombo Woodlands in South-Central Angola: A Chronosequence of Forest Recovery after Shifting Cultivation. International Journal of Forestry Research 2017; Volume 2017, 13 pages. https://doi.org/10.1155/2017/6202093

Hapsari L, Trimanto T, Budiharta S. Spontaneous plant recolonization on reclaimed post-coal mining sites in East Kalimantan, Indonesia: Native versus alien and succession progress. Biodiversitas Journal of Biological Diversity 2020; 21(5): 2003-201. https://doi.org/10.13057/biodiv/d210527

Martins WBR, Lima MDR, Udson. de Oliveira BJ, Amorim LSVB, Oliveira FA, Schwartz G. Ecological methods and indicators for recovering and monitoring ecosystems after mining: A global literature review. Ecological Engineering 2020; 145: 105707. https://doi.org/10.1016/j.ecoleng.2019.105707

Monjezi M, Shahriar K, Dehghani H, Samimi NF. Environmental impact assessment of open pit mining in Iran. Environmental Geology 2009; 58, 205-216. https://doi.org/10.1007/s00254-008-1509-4

Novianti V, Choesin DN, Iskandar DT, Suprayogo D. Plant species from coal mine overburden dumping site in Satui, South Kalimantan, Indonesia. Journal of Degraded and mining Lands management 2017; 4(4): 927-936. DOI:10.15243/jdmlm.2017.044.927. https://doi.org/10.15243/jdmlm.2017.044.927

Purnomo DW, Prasetyo LB, Widyatmoko D, Rushayati SB, Supriyatna I, Yani A. Diversity and carbon sequestration capacityof naturally growth vegetationin ex-nickel miningareain Kolaka,Southeast Sulawesi, Indonesia. Biodiversitas 2022; 23(3): 1433-1442. https://doi.org/10.13057/biodiv/d230330

Rusdy M. *Imperata cylindrica*: reproduction, dispersal, and controls. CAB Reviews 2020 15, No. 038

Safitri B, Wahyudi, Christopheros. Distribusi diameter tanaman sengon (*Paraserianthes falcataria*) sebagai indikator pertumbuhan normal. Jurnal Hutan Tropika 2020; XV (1): 43-50. https://doi.org/10.36873/jht.v15i1.1713

Soto DP, Puettmann KJ, Fuentes C, Jacobs DF. Regeneration niches in Nothofagus-dominated old-growth forests after partial disturbance: Insights to overcome arrested succession. Forest Ecology and Management 2019; 445, 26-36. https://doi.org/10.1016/j.foreco.2019.05.004

Staporn D, Marod D, Wongprom J, Diloksumpun S. Drivers of Native Species Regeneration in the Process of Restoring a Dry Evergreen Forest from Exotic Tree Plantations in Northeastern Thailand. Forests 2022; 13, 1321. https://doi.org/10.3390/f13081321

Su Y, Hu X, Wan J, Wu S, Zhang Y, Huang X, Liu Z. Physical Properties and Storage Stability of Buton Rock Asphalt Modified Asphalt. Materials 2022, 15,3592. https://doi.org/10.3390/ma15103592

Suaryana. Performance evaluation of stone matrix asphalt using indonesian natural rock asphalt as stabilizer. Intl J Pavement Res Technol 2016; 9 (5): 387-392. DOI: 10.1016/j.ijprt.2016.09.007.

Trimanto T, Hapsari L, Budiharta S. Integrating indicators of natural regeneration, enrichment planting, above-ground carbon stock, micro-climate and soil to asses vegetation succession in postmining reclamation in tropical forest. Turkish Journal of Botany 2021; **45**, 457-467. https://doi.org/10.3906/bot-2103-35

Tuheteru FD, Husna, Basrudin, Arif A, Albasri, Mustafa I. Vegetation composition in gold post-mining land of PT. Sultra Utama Nickel, Bombana District. IOP Conf. Ser.: Earth Environ. Sci. 883 012065; 2021. https://doi.org/10.1088/1755-1315/883/1/012065

Voigt M, Supriatna J, Deere NJ, Kastanya A, Mitchell SL, Rosa IMD, Santika T, Siregar R, Tasirin JS, Widyanto A, Winarni, NL, Zakaria Z, Mumbunan S, Davies ZG, Struebig MJ. Emerging threats from deforestation and forest fragmentation in the Wallacea centre of endemism. Environmental Research Letters 2021; **16**, 094048. https://doi.org/10.1088/1748-9326/ac15cd

Xiang-bin S, Gui-xiang L, Xiang-jing F, Jin-ping S, He Liping, Bi Bo. Heavy Metal Contents and Accumulation Characteristic of Dominant Plants in Tin Mining Wasteland of Gejiu city, Yunnan, China 5th International Conference on Advanced Design and Manufacturing Engineering (ICADME 2015); 2015.

Widhiyatna D, Hutamadi R, Sutrisno. Tinjauan konservasi sumberdaya aspal buton. Buletin Sumberdaya Geologi 2007; 2 (3): 42-49. DOI: 10.47599/bsdg.v2i3.218. [Indonesian]

Wiryono, Siahaan Ab. Species composition of understory vegetation in coal mined land in Central Bengkulu, Indonesia. Biodiversitas 2013; 14(1): 31-36. https://doi.org/10.13057/biodiv/d140105.