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Diversity and carbon sequestration capacity of naturally growth vegetation in ex-nickel mining area in Kolaka, Southeast Sulawesi, Indonesia

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Abstract. *Purnomo DW, Prasetyo LB, Widyatmoko D, Rushayati SB, Supriyatna I, Yani A. 2022. Diversity and carbon sequestration capacity of naturally growth vegetation in ex-nickel mining area in Kolaka, Southeast Sulawesi, Indonesia. Biodiversitas 23: 1433-1442.* Efforts to restore forest integrity on ex-mining lands are essential to improve environmental quality and sequester carbon. One such effort is through revegetation of post-mined land including in ex-nickel mining in Southeast Sulawesi. This research analyzes the diversity of naturally regenerating plant species in the ex-nickel mining area in Kolaka, Southeast Sulawesi and determines several local tree species with the potential for carbon sequestration. Vegetation survey was conducted using a systematic nested sampling method at the post-mined site with three vegetation types: secondary forest, shrubs and bushes, and a reference/control site (i.e., natural forest in the nearby Lamedai Nature Reserve). Different types of vegetation were analyzed based on factors using Discriminant Analysis. Vegetation composition was analyzed using the Importance Value Index. Furthermore, biodiversity indicators were analyzed using Shannon-Wiener Diversity Index, Species Evenness Index, and Sorensen Similarity Index. Carbon absorption was measured using the leaf sample method and carbohydrate test. The results showed that the condition of the research site had been disturbed, and the succession process was still ongoing. The species diversity at all plant levels was classified as moderate category and the distribution of the community was unstable. At the tree level, the undisturbed areas had higher diversity. Eradication of *Chromolaena odorata* was needed to preserve the native vegetation and accelerate forest succession. Tree species recommended for restoring the ex-nickel mining area and carbon sequestration as core plants include *Vitex glabrata* R.Br., *Alstonia macrophylla* Wall. ex G.Don, *Lithocarpus celebicus* (Miq.) Rehder, *Callicarpa pentandra* Roxb., *Dacryodes rugosa* (Blume) H.J.Lam, *Cananga odorata* (Lam.) Hook.f. & Thomson, *Glochidion rubrum* Blume, *Terminalia bellirica* (Gaertn.) Roxb., and *Psychotria calocarpa* Ruiz & Pav., and other pioneer plants of *Mallotus paniculatus* (Lam.) Müll.Arg., *Macaranga peltata* (Roxb.) Müll.Arg., and *Macaranga hispida* (Blume) Müll.Arg.

Keywords: Carbon sequestration, diversity, ex-nickel mining land, Kolaka, restoration

INTRODUCTION

Deforestation and forest degradation are prominent indicators of the loss of natural resources which cause a decline in the quality of human life and climate changes (Grandon et al. 2018; Agaja et al. 2020; Boteng and Marek 2021). The conversion of the world's tropical forests has caused significant carbon emissions. During 2015-2017, it contributed to an average of 4.8 billion tons of carbon emission per year, equating to about 8-10% of annual human carbon emissions (WRI 2018). Another study stated that carbon emission due to forest conversion was 2.9 billion tons per year from 2011-2015 (Federici et al. 2015).

In Indonesia, forest loss and degradation between 2001 and 2016 is primarily caused by oil palm plantations (23% of deforestation nationwide) and a lesser extent by mining (2%) (Vijay et al. 2016; Austin et al. 2019). Beyond vegetation loss, mineral extraction also results in environmental damage, especially on soil and hydrology (Kadir et al. 2020; Sievernich et al. 2021). Mining operations conducted rampantly with no regard to legally prescribed protocols could harm the natural ecosystem, particularly through the use of heavy equipment, the dumping of rock waste and tailings, the construction of several large acidic and toxic holes, and the reduction of surface water outflow (Ilham et al. 2017; Luo 2019; Stewart 2020). Open-pit mining operations have caused various damages, from micro-scale, such as reducing soil fertility to large-scale loss of primary forest to trigger climate change (Prematuri et al. 2020; Pratiwi et al. 2021). The decline in soil fertility at the local level results in low plant growth rates, which can impact the wider environment, such as erosion and the emission of methane (CH_4), CO_2, and N_2O (Noordwijk et al. 2002).

In 2019, forest destruction due to mining activities caused catastrophic floods in Southeast Sulawesi. Forests were damaged due to land conversion to plantations and mining (BNPB 2020; Kadir et al. 2020). Research by Indonesian Forum for Living Environment (*Wahana Lingkungan Hidup Indonesia*/WALHI) Region Southeast

Sulawesi found that around 640,000 hectares of forest were controlled by mining and oil palm plantations in which around 600,000 hectares were undermining concessions and 40,000 hectares were converted into oil palm plantations (Komarudin 2019). Despite the adverse environmental impacts, the mining sector accounts for 19.30% of Southeast Sulawesi's Gross Regional Domestic Product (GRDP), making it the second-largest contributor after the agricultural sector with 24.42% (BPS Provinsi Sulawesi Tenggara 2021). The mining potential is spread across ten regencies and cities, including Bombana, South Buton, North Buton, Kolaka, North Kolaka, Konawe, South Konawe, North Konawe, Muna, and Bau-Bau City (Suseno and Mulyani 2012). In some cases, unprocedural mining activities are conducted by companies with clear and clean (CNC) as well as non-clear and clean (non-CNC) statuses. This situation resulted in governmental losses, including non-registered taxes, ignorance of mining corporations to do social responsibilities to the community, and environmental harm (Kadir et al. 2020).

Strong efforts are needed to mitigate and reverse forest destruction in Indonesia to achieve sustainability. Restoring forest integrity is the most effective solution to improve environmental quality, including a reduction in atmospheric carbon concentration (Locatelli et al. 2015; Vasquez-Grandon et al. 2018). A total of 1 to 3 billion tons of carbon per year is absorbed by forests and 0.4 billion tons by forest soils (Lal 2005). In the case of Southeast Sulawesi, the government must focus on the mining industry, which remains the region's second major source of revenue after agriculture (Kadir et al. 2020). The most significant effort is to restore/reclaim degraded land after mining operations to recover various ecological functions once provided by the forest prior to mining. One of the activities in post-mining reclamation is through revegetation by planting native species on a large scale (Tang et al. 2007; Ong 2012). In revegetating post-mined land, the natural regeneration of native plants is essential to complement active planting to accelerate vegetation succession.

Understanding natural regeneration in ex-mining land is very important to select potential types of vegetation for land restoration and carbon sequestration. Postmining reclamation with intensive planting of fast-growing pioneer trees, such as *Samanea saman* (Jack.) Merr. and *Senna siamea* (Lam.) H.S.Irwin & Barneby, resulted in larger above-ground carbon storage than the pre-mining area (Trimanto et al. 2021). However, using these non-native species, which are potentially invasive, requires tight control over the impact on the wider ecosystem. Ecosystem problems by invasive species were very difficult to overcome, for example, *Acacia decurrens* (J.C.Wendl.) Wild. in Mount Merapi National Park (Sunardi et al. 2017) and *Vachellia nilotica* (L.) P.J.H. Hurter & Mabb. in Baluran National Park (Sutomo et al. 2016). Land restoration needs local tree species that can adapt to nutrient-poor soil and possess high carbon absorption and storage capacity. Therefore, this research aims to analyze the diversity of naturally regenerating plant species in ex-nickel mining area in Kolaka, Southeast Sulawesi, and to determine several local trees with the potential for carbon sequestration. The results will be used as recommendations for selecting vegetation types to restore ex-mining land with emphasis on improving biodiversity and carbon sequestration.

MATERIALS AND METHODS

Study area and period

The research was performed at an ex-former nickel mining area of PT Sultra Sarana Bumi, covering an area of ±60 ha in Lalonggolosua Village, Tanggetada Sub-district, Kolaka District, Southeast Sulawesi Province, Indonesia (Figure 1). Mining activities stopped in 2013, and then the land was abandoned until a natural regeneration process occurred (e.g., Nukdin the Head of Lalonggolosua Village 2021, pers. com.). The research site was located at 4°19'23.50"S and 121°32'31.10"E with an altitude of 44.5 m above sea level. Table 1 shows the climatic and soil conditions of the research site from April to July 2021.

Data collection procedure

Vegetation data

The survey on vegetation was conducted using a systematic sampling method using nested plots. Plots measuring 1 m x 1 m for the understory include grass, herbs and seedling, 5 m x 5 m for the poles with diameter < 10 cm, and 10 m x 10 m for trees with diameter > 10 m placed along the transect. The distance between plots was 25 m, and between transects was 50 m. The research site was divided into three vegetation types: secondary forest, shrubs and bushes based on land cover conditions. Secondary forest had a high tree density because of relatively undisturbed during mining operations. Both shrubs and bush were previously disturbed by mining activities in which shrubs had higher seedling and pole densities than bush, implying that bush was the vegetation type with the most degraded condition. As a control, an analysis of the vegetation was carried out in the Lamedai Nature Reserve as a conservation area with relatively original species. This forest was chosen because it is very close to the research site (directly adjacent in the north) and had similar environmental conditions to the research site. A total of 60 plots were successfully established, consisting of 15 plots in each of three vegetation types and a control site. Vegetation data were recorded at each plot, including species name, number of individuals, tree diameter and height.

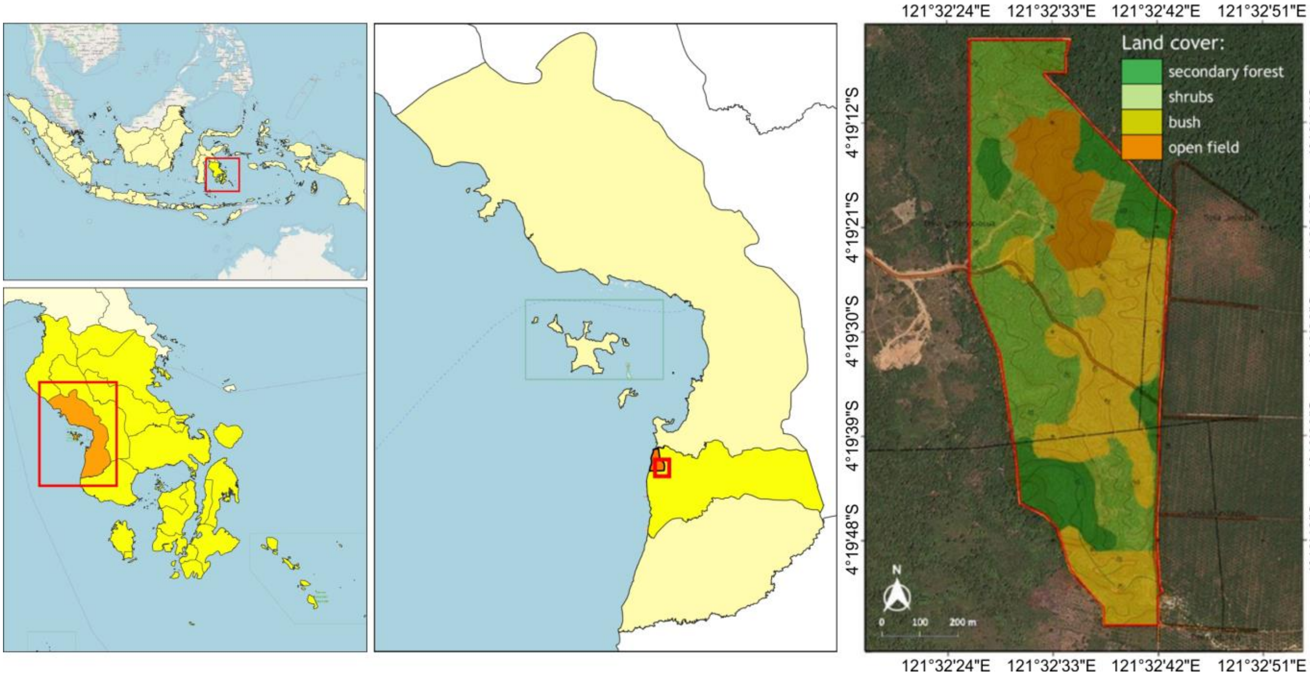

Figure 1. Map of research site in Lalonggolosua Village, Tanggetada Sub-district, Kolaka District, Southeast Sulawesi Province, Indonesia

Table 1. Climatic and soil conditions in the research site

Condition	Value
Climatic	
Temperature (°C)*	28.32 ± 0.73
Humidity (%)*	76.75 ± 3.69
Monthly rainfall (mm)*	171.89 ± 95.36
Climate type (Schmidt-Ferguson)	C (rather wet)
Soil	
pH H2O**	5.81 ± 0.77
C Organic (%)**	1.96 ± 0.71
P-Available (ppm)**	5.04 ± 0.95
Cation Exchange Capacity (cmol/kg)**	12.49 ± 7.04
Base Saturation (%)**	44.88 ± 29.30
Sand (%)***	40.60 ± 21.42
Silt (%)***	24.80 ± 10.35
Clay (%)***	34.60 ± 21.28

Source: *Meteorological Station Class III Sangia Nibandera Kolaka 2015-2020; **Chemical analysis of 10 soil samples in the site; ***Physical analysis of 5 soil samples in the site

Carbon sequestration data

Carbon sequestration ability was estimated using absorption and storage capacity. Absorption is the ability of a plant species through its leaves to absorb carbon, while storage capacity is the ability to store carbon stocks in the form of biomass. Measurement of carbon absorption used the leaf sample method (non-destructive) and carbohydrate test (Lailati 2013; Daud et al. 2019). The data included the number of leaves per tree, leaf area measurement per sample 30 g, leaf carbohydrate mass per tree species. Meanwhile, the leaves were taken at 05.00 and 10.00 to determine the difference in carbon dioxide uptake at different times. Leaf carbohydrate test was conducted at the Laboratory of Food Chemistry and Biochemistry, Department of Food Science and Technology, Faculty of Agricultural Technology, IPB.

Data analysis

The differences in the three vegetation types were analyzed based on factors using Discriminant Analysis (Ghozali 2006). Canonical discriminant analysis (CDA) is used to determine relation patterns between-class variation of several significant vegetation variables. The factors observed were the number of species, the density of each vegetation level, and the basal area. The dominant vegetation composition of each habitat type was analyzed using the Important Value Index (Mueller-Dombois and Ellenberg 1974). The species diversity index was calculated using the Shannon-Wiener formula, namely $H' = -\sum (ni/N) \ln (ni/N)$, where ni and N are the numbers of individuals of the i-th species and individuals of all species. The level of diversity of the research site is classified as low when H' = 0-2, medium H' = 2-3, and high H' > 3. Meanwhile, the community stability was determined using the Species Evenness Index (E) with the formula $E = H' / \text{Log } S$, where H' is the Shannon Index and S = number of species. The evenness of species is low when $E < 0.3$, medium $0.3 < E < 0.6$, and high $E > 0.6$. The analysis used the Sorensen Similarity Index (CC), $CC = (2 \times c) / (s1 + s2)$ to determine the similarity level of vegetation communities between types, where c is the number of species found in two vegetation types, while s1 and s2 denote the number of vegetation types 1 and 2. Community similarity occurs when $CC > 0.5$, and different communities when $CC < 0.5$. All analyzes were performed using the PAST 4.03 software (Hammer et al. 2001).

According to Meli et al. (2014), species for restoration must lean on 5 criteria, namely: dominant species, potential natural regeneration, habitat breadth, social value, and easy propagation. We used the first 3 criteria to select species for restoration and carbon sequestration which were divided into core and pioneer plants. Core plants were selected based on three criteria: maximum diameter >20 cm, dominant species with high importance in the community, and a good regeneration rate at the tiller level. Furthermore, three dominant pioneer plant species were selected, and the calculation of carbon dioxide sequestration capacity used the Carbohydrate by Different Test through a mole ratio (Avogadro's equation) 9, namely: $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$. The mass of CO_2 = 1.47 x mass of $C_6H_{12}O_6$ was analyzed by converting carbohydrates to carbon dioxide per sample leaf mass, per leaf mass per hour, and per individuals per hour. The area and number of leaves were calculated on each selected tree species at the pole level of height 1.0-1.5 m.

RESULTS AND DISCUSSION

Diversity of vegetation types

The vegetation sampling recorded 105 species from 39 families across all plant levels. Most species were from the Euphorbiaceae, followed by Fabaceae and Moraceae (Figure 2). Nine species were from the Euphorbiaceae family, including five from the genus of *Macaranga*, two from *Mallotus*, and one from *Endospermum* and *Triadica*. Table 2 shows that *Macaranga peltata* (Roxb.) Müll.Arg., *Macaranga hispida* (Blume) Müll.Arg., *Macaranga gigantea* (Rchb.f. & Zoll.) Müll.Arg., and *Mallotus paniculatus* (Lam.) Müll.Arg. were the top 10 dominant species. Genus *Macaranga* and *Mallotus* are usually pioneer plant groups that grow in disturbed forest areas (Slik et al. 2003). The adaptability of Macaranga is very high in various soil conditions and canopy gaps in tropical rain forests (Slik et al. 2003; Susanto et al. 2017). The dominance of plant family was very different from that in the natural forest used as reference (i.e. Lamedai Nature Reserve). In Lamedai NR, Myrtaceae was the most dominant family with ten species, followed by four species of Fabaceae and seven other families, including Euphorbiaceae, had three species. Two native species, *Xanthostemon petiolatus* (Valeton) Peter G. Wilson and *Tristaniopsis whiteana* (Griff.) Peter G.Wilson & J.T.Waterh. from the Myrtaceae family, were the most dominant species in Lamedai NR (Table 3).

Several native plant species were found in large numbers, including *Vitex glabrata* R.Br. (IV = 79.24%), *Lithocarpus celebicus* (Miq.) Rehder (IV = 21.15%), *Callicarpa pentandra* Roxb. (IV = 16.23%), *Dacryodes rugosa* (Blume) H.J.Lam (IV = 14.19%), and *Sarcotheca celebica* Veldkamp (IV = 5.61%) even though forest condition was disturbed (Table 2). *V. glabrata* had a fairly wide distribution from India to northern Australia (Capareda 1999; GBIF Secretariat 2021). This species grows and develops quickly because the fruit is eaten by various birds and wild mammals in the forest (de Kok 2008; Chakravarthy and Ratnam 2015). *Sarcotheca celebica* Veldkamp is an endemic species to Sulawesi (Astuti et al. 2018; GBIF Secretariat 2021). Meanwhile, *L. celebicus, C. pentandra,* and *D. rugosa* are found throughout Indonesia (GBIF Secretariat 2021). It was also found in large numbers of cosmopolitan tree species (GBIF Secretariat 2021) that grow naturally, namely *Alstonia macrophylla* Wall. ex G.Don (IV = 43.09%) and *Cananga odorata* (Lam.) Hook.f. & Thomson (IV = 12.11%) (Table 2).

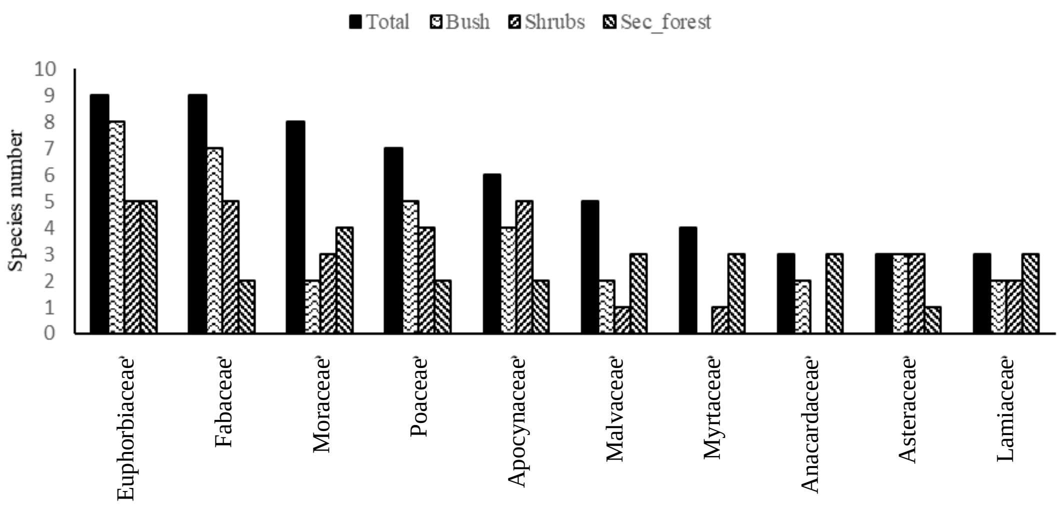

Figure 2. Top 10 family based on species number of each vegetation type at the post-mined site in Lalonggolosua, Kolaka District, Indonesia

Table 2. Important values of ten dominant plant species of each stratum at the post-mined site in Lalonggolosua, Kolaka District, Indonesia

	Species	Family	SDt	SF	SDc	IV
Understory						
1	*Paspalum repens* P.J.Bergius	Poaceae	12611.11	0.20	-	25.16
2	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Asteraceae	5611.11	0.44	-	19.08
3	*Imperata cylindrica* (L.) P.Beauv.	Poaceae	5722.22	0.16	-	12.85
4	*Mucuna pruriens* (L.) DC.	Fabaceae	5333.33	0.09	-	10.74
5	*Leuconotis griffithii* Hook.f.	Apocynaceae	2888.89	0.24	-	10.17
6	*Ageratum conyzoides* L.	Asteraceae	4555.56	0.11	-	9.95
7	*Smilax* sp	Smilacaceae	1111.11	0.31	-	8.72
8	*Tetracera alnifolia* Willd.	Dilleniaceae	4055.56	0.09	-	8.64
9	*Alstonia macrophylla* Wall. ex G.Don	Apocynaceae	1777.78	0.20	-	7.36
10	*Panicum repens* L.	Poaceae	3333.33	0.04	-	6.46
Pole						
1	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Asteraceae	1324.44	0.86	8006.28	80.20
2	*Alstonia macrophylla* Wall. ex G.Don	Apocynaceae	524.44	0.49	3524.04	36.55
3	*Lantana camara* L.	Verbenaceae	391.11	0.24	520.00	16.02
4	*Macaranga peltata* (Roxb.) Müll.Arg.	Euphorbiaceae	204.44	0.22	1131.20	13.97
5	*Cananga odorata* (Lam.) Hook.f. & Thomson	Annonaceae	204.44	0.22	935.11	13.17
6	*Psychotria calocarpa* Kurz	Rubiaceae	275.56	0.20	262.13	11.48
7	*Mallotus paniculatus* (Lam.) Müll.Arg.	Euphorbiaceae	142.22	0.18	1025.87	11.21
8	*Macaranga gigantea* (Rchb.f. & Zoll.) Müll.Arg.	Euphorbiaceae	133.33	0.16	705.78	9.22
9	*Lithocarpus celebicus* (Miq.) Rehder	Fagaceae	62.22	0.11	1304.89	9.12
10	*Macaranga hispida* (Blume) Müll.Arg.	Euphorbiaceae	115.56	0.16	746.58	9.00
Tree						
1	*Vitex glabrata* R.Br.	Lamiaceae	37.78	0.31	11892.73	62.32
2	*Alstonia macrophylla* Wall. ex G.Don	Apocynaceae	26.67	0.22	8694.36	44.71
3	*Mallotus paniculatus* (Lam.) Müll.Arg.	Euphorbiaceae	20.00	0.16	2696.98	25.88
4	*Lithocarpus celebicus* (Miq.) Rehder	Fagaceae	15.56	0.11	5106.02	24.93
5	*Callicarpa pentandra* Roxb.	Lamiaceae	13.33	0.09	3717.42	19.76
6	*Dacryodes rugosa* (Blume) H.J.Lam	Burseraceae	8.89	0.04	4910.62	16.62
7	*Cananga odorata* (Lam.) Hook.f. & Thomson	Annonaceae	8.89	0.09	2042.78	14.32
8	*Acacia auriculiformis* A.Cunn. ex Benth.	Fabaceae	4.44	0.04	2409.53	9.67
9	*Ficus callosa* Willd.	Moraceae	2.22	0.02	3532.51	9.06
10	*Sarcotheca celebica* Veldkamp	Oxalidaceae	4.44	0.04	741.40	6.65

Note: SDt: Species Density (ind/ha); SF: Species Frequency (%); SDc: Species Dominance (cm^3/ha); IV: *Important Value*

The community species diversity index at all plant levels was in the moderate category (H'= 1.91-2.99), except at the pole level in the shrubs (H' = 3.11) (Figure 3). Meanwhile, the species evenness index varied widely (E = 0.26-0.96), indicating that the distribution of the community was unstable, especially the shrub vegetation type. Secondary forest had a higher species diversity and was closer to resembling the natural forest because it was not disturbed during mining activities; hence the succession process became more quickly. At the tree level, the undisturbed area (secondary forest and natural forest) had a higher diversity of natural forest (H' = 2.71), followed by secondary forests (H' = 2.43), shrubs (H' = 2.22), and bushes (H' = 1.91). Meanwhile, the understory in the secondary forest and shrubs had moderate and low diversity. The bush vegetation type was dominated by *Chromolaena odorata* (L.) R.M.King & H.Rob. at the understory (IV = 29.29%) and pole (IV = 83.32%) levels. Chromolaena is an invasive species in various parts of the world (GBIF Secretariat 2021) and has caused different ecological and economic losses in its invaded areas (Goodal and Erasmus 1995; Zheng and Liao 2017). This species can grow rapidly by controlling the new environment, including changing soil quality according to its needs (Mandal and Joshi 2014) and producing allelopathy (Hu and Zhang 2013).

Vegetation type and succession rate

Based on the composition, all vegetation types showed significant differences (CC < 0.5) (Table 4). As the basis for categorizing vegetation types, the land cover show differences in the communities. According to the succession stage, secondary and natural forests clearly had a greater similarity value (CC = 0.18) compared to bushes (CC = 0.10) and shrubs (CC = 0.08).

Table 3. Important values of ten dominant plant species on each stratum in Lamedai Natural Reserve, Kolaka District, Indonesia

	Species	Family	SDt	SF	SDc	IV
Understory						
1	*Dinochloa scandens* (Blume ex Nees) Kuntze	Poaceae	18666.67	0.80	-	44.80
2	*Cleistanthus sumatranus* (Miq.) Müll.Arg.	Phyllanthaceae	9000.00	0.53	-	24.21
3	*Cleistanthus diversifolius* (Roxb.) Müll.Arg.	Phyllanthaceae	4666.67	0.33	-	13.55
4	*Licania* sp.	Chrysobalanaceae	4500.00	0.33	-	13.28
5	*Barringtonia racemosa* (L.) Spreng.	Lecytidaceae	3000.00	0.27	-	9.64
6	*Xanthostemon petiolatus* (Valeton) Peter G.Wilson	Myrtaceae	1666.67	0.33	-	8.62
7	*Cryptocarya ferrea* Blume	Lauraceae	4166.67	0.20	-	10.38
8	*Polyalthia* sp.	Annonacea	2500.00	0.20	-	7.64
9	Fabaceae	Fabaceae	2833.33	0.13	-	7.01
10	*Dehaasia celebica* Kosterm.	Lauraceae	1333.33	0.13	-	4.54
Pole						
1	*Cleistanthus diversifolius* (Roxb.) Müll.Arg.	Phyllanthaceae	1120.00	0.67	25852.88	54.91
2	*Barringtonia racemosa* (L.) Spreng.	Lecytidaceae	1013.33	0.87	13985.35	42.76
3	*Memecylon paniculatum* Jack	Melastomaceae	640.00	0.47	15658.13	33.48
4	*Xanthophyllum flavescens* Roxb.	Polygalaceae	186.67	0.47	3311.44	12.73
5	*Garcinia* sp.	Clusiaceae	133.33	0.27	5573.50	11.76
6	*Cleistanthus sumatranus* (Miq.) Müll.Arg.	Phyllanthaceae	240.00	0.40	1204.50	10.36
7	*Mallotus peltatus* (Geiseler) Müll.Arg.	Euphorbiaceae	240.00	0.13	3105.67	8.95
8	*Pericopsis mooniana* TWH	Fabaceae	80.00	0.13	4715.23	8.22
9	*Gnetum gnemon* L.	Gnetaceae	240.00	0.27	646.63	7.99
10	*Tristaniopsis whiteana* (Griff.) Peter G.Wilson & J.T.Waterh	Myrtaceae	240.00	0.27	549.71	7.88
Tree						
1	*Castanopsis buruana* Miq	Fagaceae	93.33	0.60	93646.26	70.13
2	*Licania* sp.	Chrysobalanaceae	73.33	0.33	40575.34	39.74
3	*Xanthostemon petiolatus* (Valeton) Peter G.Wilson	Myrtaceae	53.33	0.33	29547.40	31.64
4	*Memecylon paniculatum* Jack	Melastomaceae	26.67	0.13	29917.08	19.97
5	*Polyalthia* sp.	Annonaceae	20.00	0.13	17216.52	14.20
6	*Dacryodes rostrata* (Blume) H.J.Lam	Burseraceae	20.00	0.13	14365.50	13.23
7	*Calophyllum inophyllum* L.	Calophyllaceae	6.67	0.07	25278.31	12.04
8	*Syzygium polycephalum* Merr. & L.M Perry	Myrtaceae	20.00	0.20	2994.72	11.37
9	*Gnetum gnemon* L.	Gnetaceae	13.33	0.13	8296.14	9.72
10	*Memecylon edule* Roxb.	Melastomaceae	13.33	0.13	7666.83	9.51

Note: SDt: Species Density (ind/ha); SF: Species Frequency (%); SDc: Species Dominance (cm^3/ha); IV: *Important Value*

Table 4. Sorensen Similarity Index between vegetation types at the post-mined site in Lalonggolosua, Kolaka and the reference site, i.e., natural forest in Lamedai NR.

	Bush	Shrubs	Sec_Forest	Forest
Bush	-	0.47	0.48	0.10
Shrubs		-	0.37	0.08
Sec_Forest			-	0.18
Forest				-

The eight variables used to test the differences between vegetation types were understory density, pole density, tree density, number of understory species, number of pole species, number of tree species, pole dominance, and tree dominance. However, only four variables had normal data distribution ($P > 0.05$), which was included in the Multiple Discriminant Analysis. These included understory density ($P = 0.063$), pole density ($P = 0.154$), the number of types of pole ($P = 0.200$), and pole dominance ($P = 0.172$). Based on the canonical discriminant analysis (CDA) ordinance plot (Figure 4), the grouping of vegetation types can be explained by the square root (sq) of the understory density (u_density), pole density (p_density), the number of pole species (p_spnumber), and pole dominance (p_dominance). Furthermore, discriminant functions 1 (CAN 1) and 2 (CAN 2) explained 95.63% and 4.37% of the variation in vegetation types by these four vegetation variables.

Secondary forest had a high pole dominance value but a low understory density. The high pole dominance resulted in dense canopy cover, causing a reduction in the intensity of light entering the forest floor to inhibit the growth of understorey and shrubs (Dupuy and Chazdon 2008; Nahdi and Darsikin 2014; Udayana et al. 2020). The pole density of the secondary forest was different from shrubs, indicating that the succession process was still ongoing. The succession of the rehabilitation area takes a long time, between 10 and 40 years, to recover the vegetation composition, resembling the original forest (Correa et al. 2018; Udayana et al. 2019).

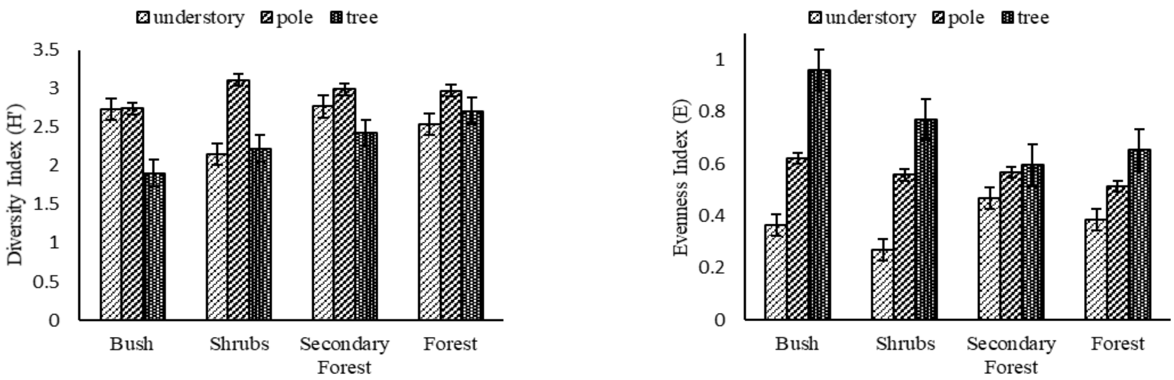

Figure 3. Diversity Index (H') and Evenness Index (E) of each vegetation type at the post-mined site in Lalonggolosua, Kolaka and the reference site, i.e., natural forest in Lamedai NR

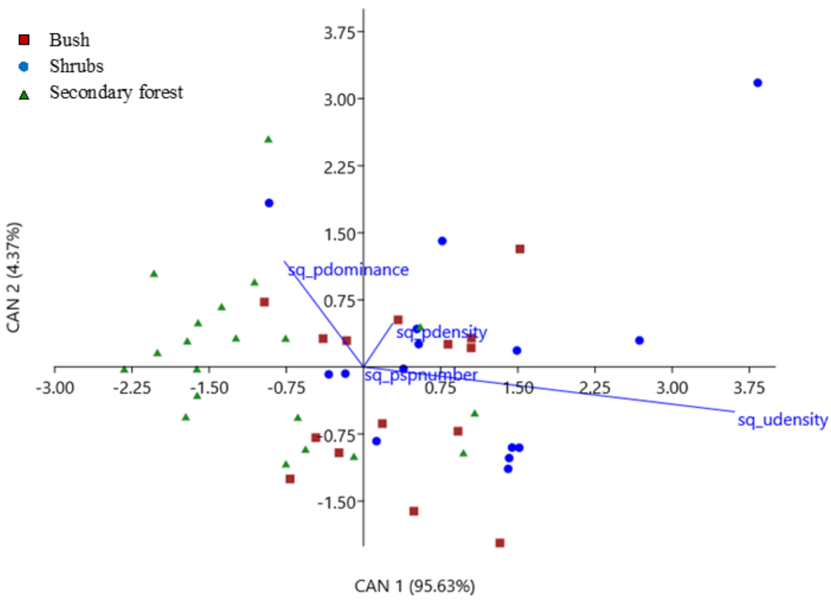

Figure 4. Ordination plot of canonical discriminant analysis (CDA)

After seven years, the vegetation composition resulting from natural regeneration at the research site showed that the pole species number in the three types of vegetation was not significantly different. The pole species number in the area undergoing natural regeneration resembled a secondary forest. One of the signs of the succession of post-mining rehabilitation vegetation is the natural appearance of poles, especially those from soil seed banks (Wiryono and Douny 2012; Soendjoto et al. 2015). In contrast, there was only a slight difference between shrubs and bushes. This is because shrubs have the most extensive ordinance space and cover the entire area. The only significant variation was in understory density, where shrubs have a larger understory density.

Natural regeneration

The vegetation analysis at the research site obtained understory plants, including grass, herbs, and seedling, with 68 species from 34 families. The understory was dominated by grasses and herbs, *Paspalum repens* P.J.Bergius (IV = 25.16), *Chromolaena odorata* (L.) R.M.King & H.Rob. (IV = 19.08), and *Imperata cylindrica* (L.) P. Beauv. (IV = 12.85) (Table 2). According to the species composition at each stage, only 11 species (35.48 %) of 27 tree species did not recover at the seedling or pole level. About 11 trees had good regeneration ability at all plant levels, namely *A. macrophylla*, *M. paniculatus*, *L. celebicus*, *C. pentandra*, *D. rugosa*, *C. odorata*, *Vitex cofassus* Reinw. ex Blume, *Gnetum gnemon* L., *Buchanania arborescens* (Blume) Blume, *Terminalia bellarica* (Gaertn.) Roxb., and *M. gigantea*.

The structure of the three vegetation types forms an inverted J-shaped curve (Figure 5). Therefore, the forest experienced succession and was at a balanced condition (Dyakov 2013; Gunawan et al. 2011). The most balanced ecosystem occurred in shrubs, where the number of understory individuals (85337 individuals/ha) and poles (6960 individuals/ha) had the highest value. The understory density in secondary forests (29893 individuals/ha) experienced population stability disturbances. In addition to the low light intensity factor (Dupuy and Chazdon 2008; Udayana et al. 2020), the gap in the secondary forest was dominated by the invasive plant *Chromolaena odorata* (L.) R.M.King & H.Rob. (Mandal and Joshi 2014; Hu and Zhang 2013). Based on the horizontal structure graph, tree density acts as the difference between secondary forest (366.67 individuals/ha), shrubs (146.67 individuals/ha), and bushes (53.33 individuals/ha). Furthermore, tree density in the secondary and natural forests was almost similar (460 individuals/ha). In contrast to individual density data, the number of species in the secondary forest was higher at the pole (35 species) and tree (19 species) levels (Figure 4). The number of pole and tree species in the secondary and natural forests was almost similar, consisting of 38 and 23 species of pole and trees. This further stated that the succession process was still ongoing with a naturally occurring regeneration pattern. The management of *Chromolaena* invasion becomes critical to ensuring that this succession process runs well.

Potential plant species for restoration and carbon sequestration

The nine tree species that met the criteria as the core plant for restoration include *V. glabrata*, *A. macrophylla*, *L. celebicus*, *C. pentandra*, *D. rugosa*, *C. odorata*, *Glochidion rubrum* Blume, *T. bellirica*, and *Psychotria calocarpa* Ruiz & Pav. Meanwhile, the three pioneer plants selected are *M. paniculatus*, *M. peltata*, and *M. hispida*. All selected species were trees with lowland habitat (0-1000 masl) (according to Plant Resources of South-East Asia www.prota4u.org**)**, and native distribution in Indonesian territory (according to Plants of the World Online www.powo.science.kew.org).

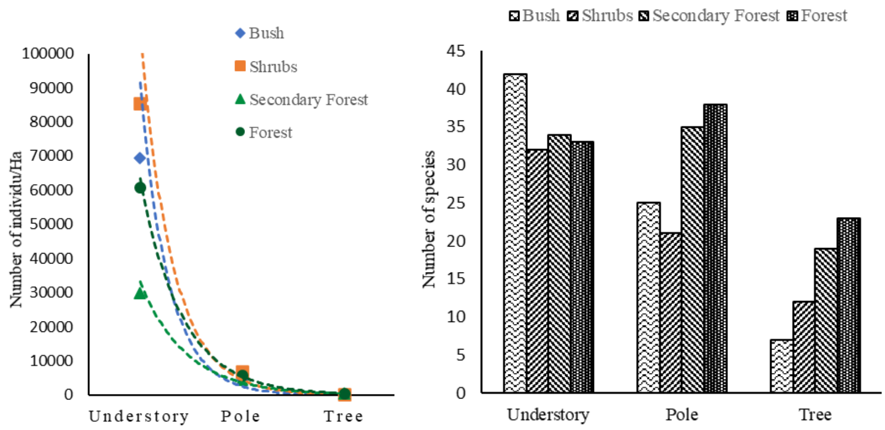

Figure 5. Regeneration structure on each vegetation type; the number of individuals per hectare and number of species

Table 5. Potential tree species for land restoration and carbon sequestration in post-mined site

	Tree species	%KH		Mass KH (g)	Mass CO_2 (g)	Total leaf Mass (g/ind)	CO_2 sink g/hr/ ind
		05.00	10.00				
Core plants							
1	*Vitex glabrata* R.Br.	73.76	74.52	0.3618	0.5319	59.9250	3.4946
2	*Alstonia macrophylla* Wall. ex G.Don	70.62	75.25	0.1384	0.2035	79.4083	1.5725
3	*Lithocarpus celebicus* (Miq.) Rehder	67.81	78.10	0.2681	0.3941	27.9911	1.0883
4	*Callicarpa pentandra* Roxb.	69.19	74.97	0.1446	0.2126	144.3773	2.9657
5	*Dacryodes rugosa* (Blume) H.J.Lam	74.85	74.55	0.0121	0.0178	73.2583	0.1271
6	*Cananga odorata* (Lam.) Hook.f. & Thomson	65.95	79.53	0.3140	0.4616	222.6500	9.9109
7	*Terminalia bellirica* (Gaertn.) Roxb.	63.83	65.89	0.3322	0.4884	111.0267	5.9303
8	*Glochidion rubrum* Blume	75.23	79.20	0.1153	0.1695	118.7910	1.9721
9	*Psychotria calocarpa* Ruiz & Pav.	69.97	73.17	0.4457	0.6552	77.7111	5.5914
Pioneer plants							
1	*Mallotus paniculatus* (Lam.) Müll.Arg.	62.27	67.03	0.0977	0.1436	60.6150	0.8617
2	*Macaranga peltata* (Roxb.) Müll.Arg.	73.48	77.86	0.0752	0.1105	50.0667	0.5406
3	*Macaranga hispida* (Blume) Müll.Arg.	67.11	73.20	0.0566	0.0833	140.2500	1.1542

The difference in the carbohydrate mass indicated the carbon dioxide absorption in plants during photosynthesis. The carbohydrate produced is directly proportional to the level of absorption. Furthermore, the mass of carbohydrates produced by the 12 selected species (Table 5) at the measurement time of 05.00 was lower than 10.00. The photosynthesis formed organic compounds (carbohydrates/ starch) to increase the species of plants with the increasing light intensity. The mass of carbon dioxide produced was directly proportional to the mass of carbohydrates. This is because C in CO_2 is related to the amount of bound C in photosynthesis. The highest CO_2 absorption occurred in *P. calocarpa* (0.66 g), followed by *V. glabrata* (0.53 g) and *T. bellirica* (0.48 g).

The highest CO_2 sequestration ability for the pole category at height 1.0-1.5 m occurred in *C. odorata* (9.91 g/hour/ind), followed by *T. bellirica* (5.93 g/hour/ind) and *P. calocarpa* (5.59 g/hour/eng). When compared with other species from the same family of Annonaceae (by same method and leaf sample mass 2.28 g), the mass of CO_2 absorbed by *C. odorata* (0.462 g) was higher than *Stelechocarpus burahol* (Blume) Hook.f. & Thomson (0.058 g) (Lailati et al. 2013). Likewise, species member of Combretaceae namely *T. bellirica* (0.488 g) was higher than *Terminalia catappa* L. (0.156 g) (Daud et al. 2019). The CO_2 sequestration ability was not always directly proportional to the mass of CO_2 absorbed due to the differences in each species' number and mass of leaves. Furthermore, *P. calocarpa* had the highest CO_2 mass but lowered CO_2 sequestration ability than *C. odorata* and *T. bellirica* due to lower total leaf mass. At the time of maturity (trees), the carbon dioxide sequestration ability is higher with the growth of the number of leaves. The sequestration ability per tree also depends on the total number of leaves on each plant species. Therefore, the number of leaves positively influences the carbon dioxide sequestration ability (Lailati 2013; Daud et al. 2019). The dominant plant species in an area have a high carbon dioxide sequestration ability when associated with adapting to their habitat.

According to Yusuf and Sinohin (1999), *C. odorata* is an evergreen tree. It can reach 10-40 m in height, 75 cm in diameter, and have single leaves alternating elliptical to ovate-oval, 13-29 cm long, and 4-10 cm wide. Cultivated *C. odorata* poles can flower between the ages of 1.5-7 years at 2 m high, while in natural forests, they only flower after reaching 9-12 m in height. In addition, *C. odorata* flowers all year round, but with a marked peak season after a period of dry weather. The tree's character strongly supports the high carbon dioxide sequestration ability throughout the year.

Psychotria calocarpa and *T. bellirica* have high sequestration ability for a certain period. In stature, *P. calocarpa* is classified as a large shrub or small tree, while *T. bellirica* is a deciduous species with a height of up to 40 m and a diameter of 2-3 m (Ong and Brotonogoro 2001; Fundter et al. 1991). The carbon dioxide sequestration ability of *V. glabrata* is higher in a mature plants than in the juvenile stages. This tree has a height and diameter of up to 25 m and 1.25 m with a fairly wide distribution (Capareda 1999; GBIF Secretariat 2021; de Kok 2008; Chakravarthy and Ratnam 2015).

The findings of these 12 tree species were very helpful for policymakers, at nationwide, in determining tree species for land restoration and carbon sequestration. These tree species were native species so they did not cause ecosystem problems, as in the case of *Acacia decurrens* (J.C. Wendl.) Wild. and *Vachellia nilotica* (L.) P.J.H.Hurter & Mabb., as well as possible similar problems by the introduced trees of *Samanea saman* (Jack.) Merr. and *Senna siamea* (Lam.) H.S. Irwin & Barneby. Another advantage of these 12 species was that they had better adaptation and natural regeneration capabilities in ex-mining areas. Of course, the ability to grow would be better if applied in other locations which had better soil nutritional than ex-mining area, appropriately in lowland ecosystems 0-1000 m asl. Finally, we recommend the use of *C. odorata* and *T. bellirica* for land restoration activities in large areas, especially for the purpose of reducing carbon emissions.

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REFERENCES

Agaja MT, Adeleke EA, Adeniyi EE, Afolayan PT. 2020. The assessment of deforestation impact towards microclimate and environment in Ilorin, Nigeria. Geosfera Indonesia 5 (3): 301-317. DOI: 10.19184/geosi.v5i3.16874.

Astuti I, Sari R, Susandarini R, Fatimatuz Z. 2018. *Sarcotheca celebica* Veldkamp: Persebarannya di Sulawesi, Status Konservasi dan Kelangkaan. J Biologi Indonesia 14 (1): 143-146. DOI: 10.14203/jbi.v14i1.3672. [Indonesian]

Austin KG, Schwantes A, Yaofeng G, Kasibhatla PS. 2019. What causes deforestation in Indonesia?. Environ Res Lett. 14: 024007.

BNPB 2020. Doni Monardo Ungkap Tiga Faktor Penyebab Banjir Bandang Luwu Utara. www.bnpb.go.id [Indonesian]

BPS Provinsi Sulawesi Tenggara. 2021. Distribusi PDRB Provinsi Sulawesi Tenggara Menurut Lapangan Usaha (Persen). www.sultra.bps.go.id [Indonesian]

Capareda EP. 1999. *Vitex glabrata* R.Br. In: de Padua LS, Bunyapraphatsara N, Lemmens RHMJ (eds). Plant Resources of South-East Asia No 12 (1): Medicinal and poisonous plants 1. PROSEA Foundation, Bogor, Indonesia.

Chakravarthy D, Ratnam J. 2015. Seed dispersal of *Vitex glabrata* and *Prunus ceylanica* by civets (Viverridae) in Pakke Tiger Reserve, North-East India: spatial patterns and post-dispersal seed fates. Trop Conserv Sci 8 (2): 491-504. DOI: 10.1177/194008291500800213

Daud M, Bustam BM, Arifin B. 2019. A comparative study of carbon dioxide absorption capacity of seven urban forest plant species of Banda Aceh, Indonesia. Biodiversitas 20 (11): 3372-3379. DOI: 10.13057/biodiv/d201134.

De Kok RPJ. 2008. The genus *Vitex* L (Lamiaceae) in the flora Malesiana region, excluding New Guinea. Kew Bul 63:17-40. DOI: 10.1007/s12225-007-9013-7
Dupuy JM, Chazdon RL. 2008. Interacting effects of canopy gap, understory vegetation and leaf litter on tree seedling recruitment and composition in tropical secondary forests. For Eco Manag 255: 3716-3725. DOI: 10.1016/j.foreco.2008.03.021.
Dyakov NR. 2013. Successional pattern, stand structure and regeneration of forest vegetation according to local environmental gradients. Ecol Balkanica 5 (1): 69-85.
Federici S, Tubiello FN, Salvatore M, Jacobs H, Schmidhuber J. 2015. New estimates of CO_2 forest emissions and removals: 1990-2015. For Eco Manag 352: 89-98. DOI: 10.1016/j.foreco.2015.04.022.
Fundter JM, de Graaf NR, Hildebrand JW, van Valkenburg JLCH. 1991. *Terminalia bellirica* (Gaertner) Roxb. In: Lemmens RHMJ, Wulijarni-Soetjipto N (eds). Plant Resources of South-East Asia No 3: Dye and tannin-producing plants. PROSEA Foundation, Bogor, Indonesia.
GBIF Secretariat 2021. GBIF Backbone Taxonomy. Checklist dataset DOI: 10.15468/39omei
Goodall JM, Erasmus DJ. 1996. Review of the status and integrated control of the invasive alien weed, *Chromolaena odorata*, in South Africa. Agr Ecosyst Environ 56: 151-164. DOI: 10.1016/0167-8809(95)00647-8
Gunawan W, Basuni S, Indrawan A, Prasetyo LB, Soedjito H. 2011. Analisis komposisi dan struktur vegetasi terhadap upaya restorasi kawasan hutan Taman Nasional Gunung Gede Pangrango. J Pengelolaan Sumberdaya Alam dan Lingkungan 1 (2): 93-105. [Indonesian]
Hammer O, Harper DAT, Ryan PD. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica.
Hu G, Zhang Z. 2013. Allelopathic effects of *Chromolaena odorata* on native and non-native invasive herbs. J Food Agric Environ 11: 878-882.
Kadir A, Suaib E, Zuada H. 2020. Mining in Southeast Sulawesi and Central Sulawesi: Shadow Economy and Environmental Damage Regional Autonomy Era in Indonesia. Proceedings of the International Conference on Social Studies and Environmental Issues (ICOSSEI 2019). Advances in Social Science, Education and Humanities Research. DOI: 10.2991/assehr.k.200214.004.
Komarudin. 2019. Lingkungan Rusak Picu Bencana di Sulawesi Tenggara. www.mongabay.co.id. [Indonesian]
Kyere-Boateng R, Marek MV. 2021. Analysis of the social-ecological causes of deforestation and forest degradation in Ghana: Application of the DPSIR framework. Forests 12 (4): 409. DOI: 10.3390/f12040409.
Lal R. 2005. Forest soils and carbon sequestration. For Ecol Manag J 220: 42-258. DOI: 10.1016/j.foreco.2005.08.015.
Lailati ML. 2013. Carbondioxide sink ability of 15 plant species collection in Bogor Botanical Garden. Widyariset 16 (2): 277-286. DOI: 10.14203/widyariset.16.2.2013.277-286.
Luo Y. 2019. Environmental problems in the mining of metal minerals. IOP Conf Ser: Earth Environ Sci 384 012195. DOI: 10.1088/1755-1315/384/1/012195.
Locatelli B, Catterall CP, Imbach P, Kumar C, Lasco R, Marin-Spiotta E, Mercer B, Powers JS, Schwartz N, Uriarte M. 2015. Tropical reforestation and climate change: beyond carbon. Restor Ecol 23:337-343. DOI:10.1111/rec.12209.
Mandal G, Joshi SP. 2014. Invasion establishment and habitat suitability of *Chromolaena odorata* (L.) King and Robinson over time and space in the western Himalayan forests of India. J Asia-Pacific Biodivers 7: 391-400. DOI: 10.1016/j.japb.2014.09.002
Meli P, Martınez-Ramos M, Rey-Benayas JM, Carabias J. 2014. Combining ecological, social and technical criteria to select species for forest restoration. Appl Veg Sci 17 (4): 744-753. DOI: 10.1111/avsc.12096.
Mueller-Dombois D, Ellenberg H. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, New York.
Nahdi MS, Darsikin. 2014. Distribusi dan kemelimpahan spesies tumbuhan bawah pada naungan *Pinus mercusii, Acacia auriculiformis* dan *Eucalyptus alba* di Hutan Gama Giri Mandiri, Yogyakarta. J Natur Indon 16 (1): 33-41. DOI: 10.31258/jnat.16.1.33-41. [Indonesian]
Ong HC, Brotonogoro S. 2001. *Psychotria viridiflora* Reinw. ex Blume. In: van Valkenburg JLCH, Bunyapraphatsara N (eds). Plant Resources of South-East Asia No 12 (2): Medicinal and poisonous plants 2. PROSEA Foundation, Bogor, Indonesia.
Ong PS. 2012. Mainstreaming native species-based forest restoration: A Synthesis-The Need to Change MAPS (Mindsets, Attitudes, and Practices). pp. 49-50. In: Neidel JD, Consunji H, Labozetta J, Calle A, Vega JM (eds) Mainstreaming Native Species-Based Forest Restoration: ELTI Conference Proceedings. Yale University, New Haven, CT; Smithsonian Tropical Research Institute, Panama City.
Pratiwi, Narendra BH, Siregar CA, Turjaman M, Hidayat A, Rachmat HH, Mulyanto, B, Suwardi, Iskandar, Maharani R, Rayadin R, Prayudyaningsih R, Yuwati TW, Prematuri R, Susilowati A. 2021. Managing and reforesting degraded post-mining landscape in Indonesia: A Review. Land 10, 658. DOI: 10.3390/land10060658.
Slik JWF, Keßler PJA, Welzen PCV. 2003. Macaranga and Mallotus Species (Euphorbiaceae) as Indicators for Disturbance in The Mixed Lowland Dipterocarp Forest of East Kalimantan (Indonesia). Ecol Indic 2: 311-324.
Soendjoto MA, Dharmono D, Mahrudin M, Riefani MK, Triwibowo D. 2015. Plant species richness after revegetation on the reclaimed coal mine land of PT Adaro Indonesia, South Kalimantan. J Manajemen Hutan Tropika 20 (3): 150-158. DOI: 10.7226/jtfm.20.3.150.
Sievernich J, Giljum S, Luckeneder S. 2021. Mining-induced deforestation in Indonesia. Identifying spatial patterns and synergies with other economic activities. Fineprint Brief No. 13, March 2021. www.fineprint.global
Stewart AG. 2020. Mining is bad for health: a voyage of discovery. Environ Geochem Health 42: 1153-1165. DOI: 10.1007/s10653-019-00367-7.
Sunardi, Sulistijorini, Titiek S. 2017. Invasion of *Acacia decurrens* Willd. after eruption of Mount Merapi, Indonesia. Biotropia 24 (1): 35-46. DOI: 10.11598/btb.2017.24.1.524.
Susanto D, Hayatudin, Setiawan A, Purnomo H, Ruhiyat D, Amirta R. 2017. Characterizing nutrient status and growth of *Macaranga gigantea* in tropical rainforest gaps after selective logging in East Kalimantan, Indonesia. Biodiversitas 18 (3): 996-1003. DOI: 10.13057/biodiv/d180318.
Suseno T, Mulyani E. 2012. Southeast Sulawesi regional development concept based on mining sector leading commodities. J Teknologi Mineral dan Batubara 8 (3): 119-131. [Indonesian]
Sutomo, Eddie VE, Wahab L. 2016. Proof of *Acacia nilotica* stand expansion in Bekol Savana, Baluran National Park, East Java, Indonesia through remote sensing and field observation. Biodiversitas 17 (1): 96-97. DOI: 10.13057/biodiv/d170114.
Tang CQ, Hou X, Gao K, Xia T, Duan C, Fu D. 2007. Man-made versus natural forests in mid-Yunnan, Southwestern China. Mount Res Develop 27: 242-249. DOI: 10.1659/mrd.0732.
Trimanto T, Hapsari L, Budiharta S. 2021. 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 J of Bot 45: 457-467. DOI: 10.3906/bot-2103-35.
Udayana C, Andreassen HP, Skarpe C. 2020. Understory diversity and composition after planting of teak and mahogany in Yogyakarta, Indonesia. J Sustain For 39 (5): 494-510. DOI: 10.1080/10549811.2019.1686029.
Van Noordwijk M, Mulia R, Hairiah K. 2002. Bahan Ajar 8. Estimasi Biomasa Tajuk dan Akar Pohon Dalam Sistem Agroforestri: Analisis Cabang Fungsional (Functional Branch Analysis, Fba) Untuk Membuat Persamaan Alometrik Pohon. WaNuLCAS Model Simulasi Untuk Sistem Agroforestri. International Centre for Research in Agroforestry Southeast Asian Regional Research Programme, Bogor, Indonesia. [Indonesian]
Vásquez-Grandón A, Donoso PJ, Gerding V. 2018. Forest degradation: when is a forest degraded?. Forests 9: 726. DOI: 10.3390/f9110726.
Vijay V, Pimm SL, Jenkins CN, Smith SJ. 2016. The impacts of oil palm on recent deforestation and biodiversity loss. PLoS One 11 (7): e0159668. DOI: 10.1371/journal.pone.0159668.
Wiryono, Douny JB. 2012. The recovery of plant species diversity in 14 year-old forest in rehabilitated mined land in Central Bengkulu. in The 2nd Society for Indonesian Biodiversity International Conference , 6-8 November 2012, Lombok, West Nusa Tenggara, Indonesia.
WRI. 2018. By the Numbers: The Value of Tropical Forests in the Climate Change Equation. www.wri.org
Yusuf UK, Sinohin VO. 1999. *Cananga odorata* (Lamk) Hook.f. & Thomson. In: Oyen LPA, Dung NX (eds). Plant Resources of South-East Asia No 19: Essential-oil plants. PROSEA Foundation, Bogor, Indonesia.
Zheng YL, Liao ZY. 2017. High-density native-range species affects the invasive plant *Chromolaena odorata* more strongly than species from its invasive range. Sci Rep 7: 16075.