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Research Article

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

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Abstract: Open-cast mining in tropical forests causes negative impacts on biodiversity and carbon storage. Postmining reclamation is therefore imposed to recover the vegetation despite the lack of understanding which indicators can be used to monitor the progress of succession. This study proposes an integrated framework to assess the trajectory of vegetation succession in coal mining site in East Kalimantan, Borneo. We combine the indicators of floristic diversity of naturally growing terrestrial and epiphytic plants, survival and growth of enrichment planting of native plants, above-ground carbon stock of pioneer trees, and the measurements on micro-climate and soil conditions. We compare some indicators across the 9-year-old and 17-year-old reclaimed sites and the premining sites. The results showed that naturally growing vegetation at the reclaimed sites was at the early to midsuccession stages, with biodiversity indicators much lower than those at the premining areas, implying the necessity of native species planting. During a six-month monitoring, the enrichment planting of native species had high rates of survival and growth. Surprisingly, the above-ground carbon at the two reclamation sites were higher, up to six times larger, than that at the premining sites. While the micro-climates had been improved, the soils in the reclaimed sites were still in poor conditions. Our findings suggest that using single parameter to monitor the trajectory of vegetation succession in postmining reclamation can be biased, and integrating several monitoring measures would provide a much better assessment.

Key words: Borneo, open-pit mining, ecological restoration, biodiversity index, survival and growth rates, tree biomass, abiotic factors

1. Introduction

Open-cast mining, such as coal mine, operated in tropical forest causes problematic issues. This method of mining requires above-ground vegetation clearing and top-soil removal (Lei et al, 2016; Saini et al., 2016). While these activities are generic in open-cast mining across many areas globally, the impacts are much more devastating in tropical regions. This is because tropical forests host a huge number of biodiversity compared to other realms (Gibson et al., 2011). For example, for the group of trees, there are 40,000- 53,000 species estimated to occur in tropical forests (Slik et al., 2015). Beside the impacts on biodiversity, the loss of vegetation due to open-cast mining in tropical forest also removes the above-ground biomass, which is rich in organic carbon. In Borneo, intact forest in lowland areas could store in average 477 ton/ha of above-ground biomass (Budiharta et al., 2014). As such, if left unchecked, open-cast mining in tropical forest could be double threats for biodiversity conservation and climate change mitigation.

Despite the devastating impacts, the mining sector has been booming in many tropical regions, including in Kalimantan (Indonesian Borneo) (Resosudarmo et al., 2009). In East Kalimantan alone, as many as 1476 coal mining permits have been issued with a total extent of 5,406,566 hectares (Subarudi et al., 2016). While generating economic benefits, stakeholders related to mining sector, especially governments, are aware with the negative consequences of open-cast mining on the environment. Therefore, a set of regulations is issued by governments to control the mining operation on the ground to minimize the impacts, including those related to postmining reclamation activities. For example, the Indonesian government through Government Regulation No. 26, 2020 states the obligation of mining permit holders to carry out reclamation on postmined site. In a more detailed regulation (The Decree of Minister of Energy and Mineral Resources No. 7, 2014), the government obligate the mining holders to revegetate the postmined land using minimum 40% of native species.

While governments have set tough measures to minimize the impacts of mining on the environment, the development of science to support such policies is regarded insufficient to become a reference in practical management (Lechner et al., 2018). This is particularly eminent for the knowledge related the ecological succession process following reclamation on postmined sites, moreover in tropical forests which is considered as the most complex ecological systems on the earth (Gardner et al., 2009). Succession is a dynamic and continuous process which occurs gradually over time. After a disturbance, succession can be happening from several decades to a century as in the case of postmined reclamation site (Brady & Noske, 2010; Popelková & Mulková, 2018). In many cases, postmined reclamation requires various interventions to assist and accelerate the succession, including geomorphological and hydrological modifications, top-soil preparation, and revegetation (Silva et al., 2018; Lowry et al., 2019; Shrestha et al., 2019). When vegetation cover is absent,

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such as in open cast mining site, assisted revegetation through direct seeding of cover crops, intensive planting of pioneer trees and enrichment planting of native plants are the common methods to improve soil quality and microclimates, and to restore the productivity and vegetation cover (Bell, 2001; Sheoran et al. 2010; Lestari et al., 2019).

While various efforts have been implemented in the revegetation of postmining reclaimed sites, it is not clear whether the progress is going toward the desired goal (Lechner et al., 2018). For example, the floristic diversity and composition in the postreclaimed site are similar with those prior to mining (McCaffrey et al., 2017), or conversely, the vegetation is dominated with exotic alien species or even covered by grasses such as *Imperata cylindrica* (Chapman et al., 1999; MacDonald, 2004). In particular, the information on what indicators that can be used to assess the succession trajectories have not been clearly defined yet. Previous studies on the monitoring of succession progress in postmining reclamation site mostly focused on one or two indicators, such as above-ground carbon (e.g., Ahirwal & Maiti, 2017; Ahirwal et al., 2017), or natural regeneration and soil conditions (e.g., Novianti et al., 2018). We argue that considering solely single measure of succession indicator could be misleading, since such measure does not necessarily represent ecological integrity of the whole landscape.

Here, we develop a unique, yet simple, approach of using the combined measures of biodiversity indicators of recolonizing (naturally-grow) terrestrial and epiphytic plants, the survival and growth of enrichment planting of native species, above-ground carbon stock of pioneer trees, and the variables of micro-climate and soil to assess the trajectory of vegetation succession in reclaimed coal mining sites in East Kalimantan, Indonesian Borneo. We compare some of such measures among three different sites, i.e. a 9-year-old reclaimed site, a 17-year-old reclaimed site, and premining sites, in order to investigate the direction of the succession progress. All the parameters observed in this study are very common in ecological assessments so that our proposed framework has high practicality when implemented by stakeholders in the mining sector such as government, mining companies, and environmental consultancies.

2. Materials and methods

2.1. Study location

This research was conducted in 2018 at a coal mining concession area in Berebas Pantai, Bontang Municipality, East Kalimantan Province, Indonesia. Geographically, the research area was located at the coordinates of 00°09'32.6" N and 117°16'02.6" E to 00°09'33.8" N and 117°16'00.6" E (Figure 1). The area has an altitude of 37–174 m above sea level (asl). It has wet tropical climate with average annual rainfall of 2001–2150 mm^3/year, average temperature of 24.6 °C–33.4 °C and air humidity of 54%–89%. Based on ecoregion, the study area is categorized as lowland tropical forest (Wikramanayake et al., 2002; Budiharta et al., 2014). Prior to mining, the area was a secondary forest following selective logging with some extent of disturbances due to forest fires occurred in 1997 when extensive fire events widespread across Kalimantan.

Data were collected at three sites, namely a reclamation area of 9 years old, a reclamation area of 17 years old, and premining areas with existing vegetation cover remained. In the context of this study, the premining sites served as the reference site for the succession process occurring in the reclamation sites (Hernandez-Santin et al., 2021). The rationale of choosing the premining site as the reference area because this site is considered as the initial state of the landscape before the mining operation began. Using this framework, we assumed that any kinds in the landscape (e.g., biodiversity, carbon stock, soil properties) that were lost due to the mining activities need to be compensated/offset to accord with no-nett loss framework (Budiharta et al., 2018).

The operation of mining and reclamation activities in the studied area can be described as follow. The reclamation areas were mined by removing and dumping top soils. After the coal was mined, the top soils were returned and conditioned, and cover crops of Legume were spread. Then, pioneer tree species, such as *Albizia saman*, *Albizia falcataria* and *Senna siamea*, were planted intensively. Several native species were then planted under the pioneer trees to accelerate the closure of canopy cover at various layers and to accord with the Indonesian government regulations of achieving 40% of native species cover. Beside the planted species, several plant species also grew naturally in the reclaimed sites (spontaneous recolonization), either those which grew on the ground (i.e.

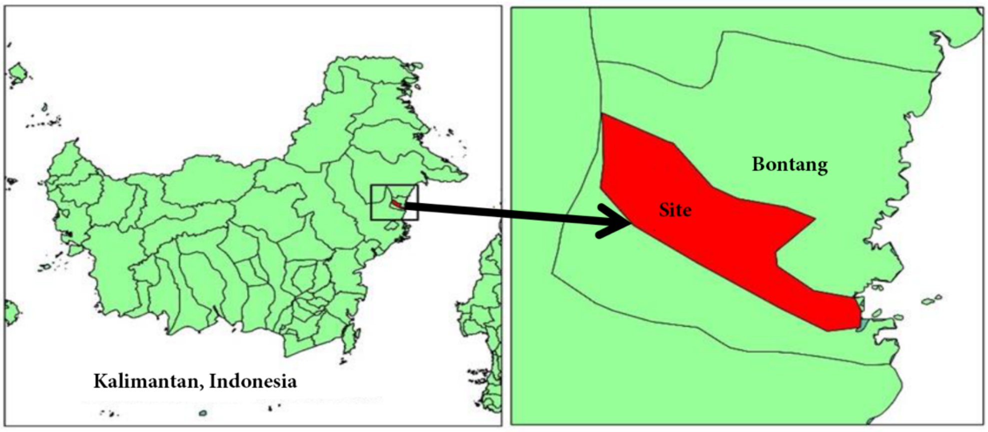

Figure 1. Map showing the location of the study at a coal mining concession area in East Kalimantan, Indonesia.

terrestrial plants) or attached on the pioneer trees as epiphytic plants.

2.2. Procedure

2.2.1. Vegetation analysis of naturally-grow terrestrial plants

Vegetation analyses of naturally-grow terrestrial plants were carried by determining the composition and structure of vegetation using the parameter of Importance Value Index (IVI), and calculating diversity indices (i.e. Shannon–Wiener diversity index, species richness index and the evenness index) (Magurran, 1983; Kent & Coker, 1992; Agbelade et al., 2017). When the study was conducted, there were only two strata of naturally-grow terrestrial plants on both the 9-year-old and the 17-year-old reclaimed sites, i.e. ground-cover/understorey and saplings (tree species at juvenile stage with a diameter of less than 7 cm), while the more mature plants were absent. Accordingly, the analyses of IVI and diversity indices were applied to the two strata. We established plots with size of each plot measuring 2×2 m for the ground-cover/understorey, while those for saplings had size of 5×5 m each plot. The IVI was the aggregation of the parameters of density, frequency and dominance, and it was formulated as:

IVI = RD (relative density) + RF (relative frequency) + RD (relative dominance).

The floristic diversity parameters were:

- The Shannon–Wiener diversity index (H') was calculated using the equation

$H' = -\Sigma\, pi \times \ln pi$; and $pi = ni/N$

in which ni = number of individuals of species I, N = total individuals of all species. The diversity level (H') can be classified into three classes, i.e. low if H' <1; moderate if 1 ≤ H ≤ 3, and high if H > 3

- Species richness index (R) was calculated using the formula:

$R = (S-1) \div \ln (N)$

in which S = total number of species, N = total number of individual species. The species richness is low if R < 3.5; moderate if 3.5 ≤ R ≤ 5.0; and high if R > 5

- The evenness index (E) was calculated as:

$E = H \div \ln (S)$

in which E = evenness index, H = diversity index, S = number of species. The evenness is small (the community has low distribution among species) if 0 < E ≤ 0.4; moderate if 0.4 < E ≤ 0.6; and high (the community has equal distribution among species) if 0.6 < E ≤ 1.0

2.2.2. Vegetation analyses of naturally-grow epiphytic plants

Vegetation analyses of epiphytic plants were carried out on plants, which were attached on the pioneer trees at the 9-year-old reclaimed site. In total, as many as 102 pioneer trees in 14 plots (with a size of 8 m x 8 m per plot) were sampled to record all epiphytic plants attached on such trees. The parameters observed were the name of epiphytic plant species, host tree species and epiphytic plant growing zone on the host tree. The growing zone of epiphytic plant was recorded based on the methods by Johansson (1975), which divides the area of host trees into 5 zones: Zone 1 is the base (1/3 part) of the main trunk; Zone 2 is the upper area (2/3 area) of the main trunk to the first branch; Zone 3 is the base (1/3 part) of the branches; Zone 4 is the middle part of the branch (1/3 of the middle part); Zone 5 is the outermost area of branching (1/3 part of the outermost branching) (Figure 2).

The importance of epiphytic plant species was analyzed by calculating the relative frequency. Frequency (F) is the chance of encountering a species in a community, which was obtained from the equation:

F = (Number present of fern or orchid in each host tree ÷ Total number of all phorophytes host tree) × 100 %

In this study, the host tree was considered as a plot. The results of frequency calculation were used to measure the relative frequency (FR). Relative frequency is the frequency of individual species (Fi) as a proportion of the total frequencies of all species found in the plot. FRi was calculated by the formula:

FRi = (Individual frequency of species i ÷ Total frequency of all species) × 100 %

The vertical distribution of epiphytic plants on the host tree was calculated based on the number of individual epiphytic species on the host tree distributed in each zone (5 zones). The percentage of epiphytic plant in each zone was calculated from the number of epiphytic species present in each zone divided by the total presence in all zones then multiplied by 100%.

2.2.3. The growth and survival of the planted native species

The growth and survival of the native plants planted/enriched at the 9-year-old reclamation site were monitored. The first monitoring (March 2018) was conducted at the age of three years old after the planting, and then they were remonitored six months after the first assessment (September 2018) to evaluate the growth and survival rates of the planted native plants. As many as 150 individuals of native plants planted were monitored, consisting of 50 species, 44 genera and 27 families. Among them, 143 plants belonged to group trees, while the other seven plants were shrubs, climber, and herbs. The following variables were recorded and measured,

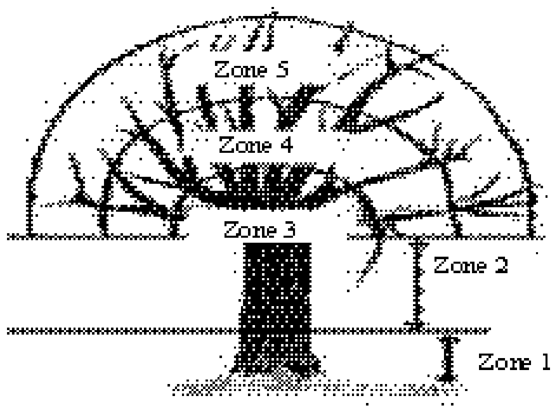

Figure 2. Growing zones of epiphytic plants in a host tree as described by Johansson (1974) (Source of Figure: Trimanto and Danarto 2020).

including name of species, plant height, diameter at 20 cm, branch free height and location of the plant at the plot.

2.2.4. Carbon stock of pioneer trees

We established as many as 25 observation plots with a size of 20 m × 20 m each plot to measure the carbon stock of pioneer trees. The calculation of carbon stock of pioneer trees used the method developed by Chave et al. (2005) as follow:

K = Tree volume × wood density × 0.5

Tree volume was calculated using the formula:

$V = \frac{1}{4} \pi D^2 \times T \times AB$,

in which $\pi = 3.14$, D = Tree diameter at breast height (1.3 m), T = Tree height and AB = Constant value of tree geometric shape (form factor). The wood density data were obtained from the database http://www.wood-database.com/ and global wood density database (Zanne et al., 2009), while the form factor of trees used a constant of 0.6 based on Krisnawati et al. (1996).

2.2.5. Abiotic factors

Several abiotic factors were measured including soil physical and chemical properties, temperature, humidity, light intensity and altitude. Soil samples were collected at each location at a depth of 0–30cm and 30–60 cm, each with three replications. The physical properties of the soil were analyzed, including soil texture (sand, silt and clay), while the chemical factors included pH value, organic C, total N, C/N ratio, P, K, Fe, Mn, cation exchange capacity, base saturation and Al saturation. A mixture of soil and water extract with composition of 1:5 was used to measure soil acidity. Walkley–Black method was used to determine C organic content, Kjeldahl method to determine N total, Bray I method to measure P, extraction method to analyze exchangeable base cations (K^+, Na^+, Ca^{2+}, and Mg^{2+}) with ammonium acetate and acidic cations (Al^{3+}, H^+) with sodium chloride, and Morgan method to determine K, Fe and Mn (Bray & Kurtz 1945; Jones 1973; Kjeldahl 1883; Walkley and Black 1934). We compared the results of our soil analysis with the threshold value of soil physical and chemical characteristics referred to Center for Soil and Agro-Climate Research (1983). Statistical tests were analyzed by SPSS 16.0. The Duncan test is used to determine the difference with 95% confidence level.

3. Results

3.1. Vegetation analysis of naturally-grow terrestrial plants

The results revealed that the diversity of naturally-grow terrestrial vegetation in the two reclamation sites had a moderate level, both at the understorey and saplings strata (Table 1). Nonetheless, the number of understorey species at the two reclamation sites was more than that of saplings, suggesting that ground cover plants are more adaptable to the harsh environmental conditions in mine reclamation areas. We also found that that the richness of understorey vegetation was high, while that of saplings was moderate at the two reclamation sites. The evenness index of the two reclamation sites showed that both understorey and saplings had a high evenness, indicating that the community had equal distribution among species with a less tendency of being dominated by particular species. Therefore, based on the measures of the diversity, richness and evenness index of plant species at both vegetation strata, the reclamation efforts had improved the environmental conditions of the post mined areas which is indicated by the natural-growth of various terrestrial plants in the reclamation areas.

When compared with vegetation condition prior to mining, all diversity indicators of the two reclamation sites showed much lower values, except for evenness index (Table 1). For example, the premining areas had three times more in the number of species and richness index than those at the two reclamation sites, both for understorey vegetation and saplings. The diversity index and richness index of understorey vegetation and saplings at the premining areas were also much higher than those at the two reclamation sites.

The results of the vegetation analysis looking at the floristic structure and composition showed that there were differences in the species composition between the reclamation sites and the premining sites (Table 2). At the premining sites, *Lygodium circinatum* dominated the understorey layer, while the most dominant species at the 9-year-old and 17-year-old reclamation sites were *Polytrias indica* and *Asystasia gangetica*, respectively. In addition, at the saplings layer, *Clerodendrum* sp. dominated the premining sites while that at the 9-year-old and the 17-year-old reclamation sites were *Glochidion obscurum* and *Macaranga tanarius*, respectively.

Based on the important value index, the understorey vegetation at the two reclamation sites were mostly composed by grasses, shrubs, herbaceous and lianas. This was different with the premining areas which were dominated by ferns species. At the sapling strata, species from the family of Euphorbiaceae and Phyllantaceae dominated the reclamation

Table 1. Comparison of plant diversity indicators at postmining reclamation sites and premining areas.

No	Site	Diversity index (H’)	Evenness index (E)	Richness index (R)	Number of species
1	Premining areas				
	Understorey layer	4.05 (high)	0.87 (high)	15.80 (high)	106 species
	Sapling layer	3.69 (high)	0.86 (high)	12.12 (high)	73 species
2	The 9-year-old reclamation site				
	Understorey layer	2.62 (moderate)	0.72 (high)	5.71 (high)	38 species
	Sapling layer	2.68 (moderate)	0.89 (high)	4.32 (moderate)	20 species
3	The 17-year-old reclamation site				
	Understorey layer	2.45 (moderate)	0.68 (high)	5.71 (high)	40 species
	Sapling layer	2.56 (moderate)	0.86 (high)	3.97 (moderate)	23 species

Table 2. Species with the highest important value index (IVI). The full list of species is provided in Appendix I.

No	The 9-year-old reclamation site		The 17-year-old reclamation site		Premining areas	
	Understory layer	Sapling layer	Understory layer	Sapling layer	Understory layer	Sapling layer
1	*Polytrias indica*	*Glochidion obscurum*	*Asystasia gangetica*	*Macaranga tanarius*	*Lygodium circinatum*	*Clerodendrum* sp.
2	*Asystasia gangetica*	*Melastoma malabathricum*	*Polytrias indica*	*Callicarpa longifolia*	*Leea angulata*	*Leea angulata*
3	*Scleria scrobiculata*	*Senna siamea*	*Callicarpa longifolia*	*Canthium glabrum*	*Donax canniformis*	*Macaranga tanarius*
4	*Clidemia hirta*	*Mallotus japonicus*	*Scleria scrobiculata*	*Melastoma malabathricum*	*Nephrolepis exaltata*	*Homalanthus populneus*
5	*Piper aduncum*	*Glochidion littorale*	*Canthium glabrum*	*Mallotus japonicus*	*Derris elliptica*	*Ficus geocarpa*

sites, in contrast with the premining site which was dominated by species from Lamiaceae and Vitaceae families.

3.2. Vegetation analysis of epiphytic plants

The inventory of epiphytic plants attached on pioneer trees at the reclamation site obtained 14 species consisted of eleven species of ferns and three species of orchids. Species of ferns attached on pioneer trees were *Pyrrosia piloselloides, P. lanceolata, P. longifolia*, *Microsorum pustulatum*, *Drynaria quercifolia, Asplenium nidus, Lygodium circinatum, L. flexuosum, L. microphyllum,* and *Nephrolepis exaltata*. The species of orchids found were *Dendrobium crumenatum, D. anosmum* and *Acriopsis indica.* In general, the epiphytic plants grew well on pioneer trees at the reclamation site. The epiphytic plants were dominated by fern species with *Pyrrosia piloselloides* was the most dominant species with the highest relative frequency of 34.69%, followed by *Asplenium nidus* (11.43%) and *Microsorum pustulatum* (10.61%) (Figure 3). On the other hand, the orchid species had moderate (*Dendrobium anosmum*) and low dominance (*Dendrobium crumenatum* and *Acriopsis indica*).

Based on the growing zone, the epiphytic plants occupied various zones on the host trees, from zone 1 to zone 5 (Table 3). Nonetheless, the epiphytic orchids tended to grow only on zones 2, 3 and 4, while the epiphytic ferns grew on all zones. The most abundant ferns, *Pyrrosia piloselloides* and *P. longifolia*, were found to have the widest vertical distribution, ranging from zone 1 to zone 5, while the epiphytic orchids mostly grew on zone 2 and zone 3. Among all growing zones,

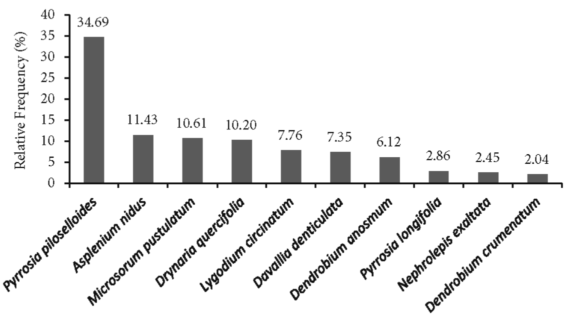

Figure 3. Ten species of epiphytic plant attached on pioneer trees at the reclamation site with the highest relative frequency.

we found that zone 2 (the area covering the main trunk of the host tree until the first branch) was the zone where the most abundant epiphytic plants were found. The total presence of epiphytes in this zone was 33.71%, followed by zone 1 (the base of the host tree) with 25.56%, and then zone 3 (the base of the branches) with 25.22% (Table 3).

The host trees of the epiphytic plants in the reclaimed site were from the legume family, including *Senna siamea* and *Albizia saman*. The frequency of the presence of epiphytes in *Senna siamea* was greater than that in *Albizia saman* (Table 4). A total of 13 species of epiphytes grew on *Senna siamea* trees, consisting of three species of orchids and ten species of ferns, while there were only nine species of epiphytic plants grew on *Albizia saman* trees, consisting of six fern species and three orchid species.

3.3. The survival and growth of the planted native species

In general, the native plant species planted in the reclamation area could adapt and grow well (Table 5). Most of the planted

Tabel 3. Growing zone of epiphytic plants on pioneer trees at the reclamation site.

No	Species name	Plant group	Growing zone				
			1	2	3	4	5
1.	*Acriopsis indica*	Orchid		3		2	
2.	*Asplenium nidus*	Fern	20	7	6	1	
3.	*Davallia denticulata*	Fern		13	8	3	
4.	*Dendrobium anosmum*	Orchid		6	9	7	
5.	*Dendrobium crumenatum*	Orchid		1	1	1	
6.	*Drynaria quercifolia*	Fern	10	10	7	3	
7.	*Lygodium circinatum*	Fern	20	13	3		
8.	*Lygodium flexuosum*	Fern	1	1	1		
9.	*Lygodium microphyllum*	Fern	1	1			
10.	*Microsorum pustulatum*	Fern	13	20	11	2	
11.	*Nephrolepis exaltata*	Fern	4	2	3		
12.	*Pyrrosia lanceolata*	Fern	1	3	2		
13.	*Pyrrosia longifolia*	Fern	4	7	4	3	3
14.	*Pyrrosia piloselloides*	Fern	45	64	58	33	7
	Total number of clumps in each zone		119	151	113	55	10
	Percentage (%)		26.56	33.71	25.22	12.28	2.23

native plants belong to the family of Euphorbiaceae, followed by Annonaceae, Dilleniaceae, Dipterocarpaceae, Sterculiaceae and Anacardiaceae. After six months of observation, out of 150 plant individuals measured, as many as 145 plants were able to survive and five died, resulting in the survival rate of all planted native species of 97%. The dead plant species were *Alstonia scholaris, Miliusa horsfieldii, Dillenia excelsa, Callicarpa arborea* and *Mezzettia* sp.. At the age of approximately three years after being planted in the reclamation area, the native plants cultivated had an average trunk diameter (20 cm above the ground) of 1.69 cm. After six months, the enriched plants had average increase in stem diameter of 0.28 cm and plant height of 19.24 cm.

Native tree species with the fastest grow rates are shown in Tables 6 and 7. *Glochidion obscurum* had the highest increase in diameter with 1.04 cm over a period of six months, followed by *Ficus geocarpa* with 0.89 cm and *Carallia brachiata* with 0.70 cm. On the other hand, species with the highest growth rate in height were *Ficus sp.*, *Carallia brachiata* and *Artabotrys* sp. with height increments of 149, 135 and 111 cm, respectively. Some species from Dipterocarpaceae, a family unique to Bornean lowland forest, namely *Shorea balangeran*, *Shorea* sp., and *Shorea leprosula* had an increase in stem diameter of 0.48, 0.4 and 0.38 cm, respectively.

Table 4. Distribution of epiphytic plants attached on pioneer trees in the reclaimed site.

No	Host tree species	Frequency (%)	Number of species
1	*Senna siamea*	55.10	13 spesies
2	*Albizia saman*	44.90	9 spesies

Table 5. The growth and survival rate of the planted native species in the reclamation site.

Indicators	Results
Number of species observed	50 species
Number of individuals observed	150 individuals
Survival rate of individuals after six months	97%
Average diameter at 3 years old	1.69 cm
Average increase of diameter after six months	0.28 cm
Average increase of height after six months	19.24 cm

3.4. Above-ground carbon stock of pioneer trees

The above-ground carbon stock of pioneer trees increased along with the age of reclamation (Table 8). Surprisingly, in average, the carbon stock of pioneer trees at the reclamation sites was much higher than the carbon stored in the above-ground vegetation at the premining sites. The 17-year-old reclamation area had almost six times more carbon (129.58 ton/ha) than that at the premining sites (23.07 ton/ha), while the 9-year-old reclamation site had almost four times (90.42 ton/ha). Nonetheless, the carbon stored in the reclamation sites was still much less than that in lowland primary forest in Kalimantan (222 ton/ha; Krisnawati et al, 2014) or even secondary forest with a lower level of disturbances (178 ton/ha; Krisnawati et al, 2014).

3.5. Abiotic factors

In general, there were differences in abiotic factors between the reclamation sites and premining areas although several of them were not significant (Table 9). In term of climate variables, the humidity of the premining areas at its average value (82.67%) was higher than that of the 9-year-old reclamation site (77%), but it was lower than that of the 17-year-old reclamation site (84%). The premining areas also had lower light intensity than that of the two reclamation sites, suggesting a denser canopy in the premining areas.

In term of soil properties, the reclaimed sites had a lower average pH value than that in the premining sites, suggesting that the soil in the reclaimed sites were still more acidic. In addition, the premining sites also had higher values of C organic, N total and C/N ratio than those in the reclaimed sites, implying that soil fertility in the reclaimed sites was not

Table 6. Fifteen native tree species with the fastest grow rates in diameter. The full list of species is provided in Appendix II.

No	Species name	Family	Diameter at three years old (cm)	Diameter after six months (cm)	Diameter increase after six months (cm)
1.	*Glochidion obscurum*	Phyllanthaceae	2.07	3.11	1.04
2.	*Ficus geocarpa*	Moraceae	1.18	2.07	0.89
3.	*Carallia brachiata*	Rhizoporaceae	3.60	4.30	0.70
4.	*Ficus* sp.	Moraceae	1.75	2.40	0.65
5.	*Cleistanthus acuminatus*	Phyllanthaceae	1.91	2.49	0.58
6.	*Shorea balangeran*	Dipterocarpaceae	1.90	2.38	0.48
7.	*Tabernaemontana divaricata*	Apocynaceae	1.27	1.75	0.48
8.	*Tabernaemontana* sp.	Apocynaceae	1.27	1.75	0.48
9.	*Guioa pleuropteris*	Sapindaceae	1.91	2.39	0.48
10.	*Croton* sp.	Euphorbiaceae	1.82	2.23	0.41
11.	*Bridelia stipularis*	Phyllanthaceae	1.02	1.43	0.41
12.	*Shorea* sp.	Dipterocarpaceae	1.61	2.02	0.40
13.	*Shorea leprosula*	Dipterocarpaceae	2.40	2.78	0.38
14.	*Guioa* sp.	Sapindaceae	1.90	2.28	0.38
15.	*Ficus callosa*	Moraceae	1.86	2.23	0.37

Table 7. Fifteen native tree species with the fastest grow rates in height. The full list of species is provided in Appendix II.

No	Species name	Family	Height at three years old (cm)	Height after six months (cm)	Height increase after six months (cm)
1.	*Ficus* sp.	Moraceae	85	234	149
2.	*Carallia brachiata*	Rhizoporaceae	310	445	135
3.	*Artabotrys* sp.	Annonaceae	100	211	111
4.	*Glochidion obscurum*	Phyllanthaceae	264	359	96
5.	*Ficus geocarpa*	Moraceae	155	248	93
6.	*Syzygium* sp.	Myrtaceae	211	301	90
7.	*Guioa pleuropteris*	Sapindaceae	329	403	74
8.	*Mussaenda frondosa*	Rubiaceae	100	170	70
9.	*Cleistanthus acuminatus*	Euphorbiaceae	200	263	63
10.	*Shorea leprosula*	Dipterocarpaceae	213	270	56
11.	*Dryobalanops lanceolata*	Dipterocarpaceae	224	278	55
12.	*Guioa* sp.	Sapindaceae	237	290	53
13.	*Bridelia stipularis*	Phyllanthaceae	139	187	48
14.	*Shorea balangeran*	Dipterocarpaceae	270	318	48
15.	*Euodia glabra*	Rutaceae	213	254	41

Table 8. Comparison of carbon stock in the reclamation sites and premining area.

Location	Minimum-maximum carbon stock (ton/ha)	Average of carbon stock (ton/ha)
9-year-old reclamation site	52.47–133.30	90.42
17-year-old reclamation site	30.70–244.37	129.58
Premining area	5.93–79.96	23.07
Primary lowland forest in Kalimantan (Krisnawati et al., 2014)	-	222
Secondary lowland forest in Kalimantan (Krisnawati et al., 2014)	-	178

yet equal as in the premining sites. The mineral contents showed varying conditions between the premining areas and the reclamation sites. Both the premining areas and the reclaimed sites contained a low amount of P (phosphorus) and a high amount of potassium, with the highest potassium content found at the younger reclamation site. The cation exchange capacity (CEC) at all sites was categorized as low, while the base saturation value (BS) was low at the older reclamation site and moderate at the younger reclamation site. This value indicates that the available cations for plants are low. Based on the soil properties overall, the reclamation sites had poor soil conditions although these conditions were not far below the premining areas.

4. Discussion

Vegetation succession is a continuous process, moreover on postdisturbance landscapes, such as in open cast mining land. In this study, we proposed a simple framework of integrating biotic and abiotic variables to assess the trajectory of vegetation succession in a postcoal mining reclamation in Bornean lowland forest, a globally significant area in terms of biodiversity and carbon storage. In doing so, we combined several measures, i.e., biodiversity indicators of naturally-grow terrestrial and epiphytic plants, the growth and survival of enrichment planting of native species, above-ground carbon stock of pioneer trees, and abiotic factors. In previous studies, such measures were common to apply separately (e.g., Ahirwal et al., 2017; Gastauer et al., 2018) with lack of context of tropical forests.

In the context of the studied area, the outcome of revegetation efforts in the reclamation sites indicated that the natural regeneration at the reclaimed sites were at the early to mid-succession stages. Although the diversity, richness and evenness indicators of naturally recolonizing terrestrial vegetation were at moderate to high levels, these only occurred on two strata of vegetation, namely understorey and saplings (Table 1). Even until the age of 17 years of reclamation, the more mature vegetation that grew spontaneously had not been found. Our findings regarding natural regeneration of understorey and saplings plants were in accordance with Novianti et al. (2018) who also found rapid recolonization of ground cover vegetation, especially for graminoids, herbs and shrubs, in a postcoal mining site in South Kalimantan five years after reclamation began. Yet, due to the absence of a more mature vegetation, our study suggests that the recovery was not so rapid as stated by Novianti et al., (2018).

When compared to the premining areas, which were degraded forests following selective logging and fires, the floristic diversity indicators at the reclaimed sites were much lower (Table 1). Our results strengthened previous study which found a low similarity in species composition of the

Table 9. Comparison of abiotic factors in the premining and reclamation sites. Similar letter in the same line shows no significant difference at the 95% confidence level with Duncan's test. Data are mean (±) standard deviations (SD).

Abiotic factors	Premining site	9-year-old reclamation site	17-year-old reclamation site
Climate variables			
Altitude (m asl.)	81.67 ± 4.51^{a}	123.67 ± 12.10^{b}	166.33 ± 7.09^{c}
Relative humidity (%)	82.67 ± 6.51^{a}	77.00 ± 15.59^{a}	84.00 ± 3.40^{a}
Temperature (°C)	26.87 ± 1.76^{a}	29.47 ± 3.69^{a}	26.27 ± 1.21^{a}
Light intensity (lux)	1128.00 ± 802.46^{a}	5086.67 ± 4163.30^{a}	2722.67 ± 2246.88^{a}
Soil properties			
pH	5.28 ± 1.02^{a}	4.70 ± 0.05^{a}	4.44 ± 0.10^{a}
C organic (%)	2.42 ± 0.76^{b}	1.27 ± 0.11^{a}	1.04 ± 0.38^{a}
N total (%)	0.30 ± 0.07^{a}	0.23 ± 0.07^{a}	0.21 ± 0.03^{a}
C/N ratio	7.63 ± 4.41^{a}	5.91 ± 1.76^{a}	4.89 ± 2.06^{a}
P_2O_5 Bray-1 (ppm)	6.13 ± 2.34^{a}	5.89 ± 4.37^{a}	7.60 ± 1.60^{a}
K_2O HCl (ppm)	70.37 ± 3.20^{a}	98.89 ± 3.33^{b}	68.89 ± 3.33^{a}
Fe (ppm)	16.31 ± 0.50^{b}	10.71 ± 4.95^{b}	1.92 ± 1.35^{a}
Mn (ppm)	0.36 ± 0.09^{a}	6.25 ± 0.19^{b}	0.80 ± 0.09^{b}
K^+ (meq./100g)	0.51 ± 0.03^{a}	1.01 ± 0.06^{b}	0.83 ± 0.36^{ab}
Na^+ (meq./100g)	0.25 ± 0.04^{a}	0.41 ± 0.05^{b}	0.39 ± 0.08^{b}
Ca^{2+} (meq./100g)	1.34 ± 0.50^{a}	1.09 ± 0.15^{a}	1,48 ± 0.81^{a}
Mg^{2+} (meq./100g)	0.67 ± 0.25^{a}	0.86 ± 0.16^{a}	0.85 ± 0.37^{a}
Base saturation (%)	37.87 ± 20.00^{a}	43.97 ± 5.32^{a}	29.97 ± 3.85^{a}
CEC saturation (meq./100g)	7.53 ± 1.52^{a}	7.67 ± 0.46^{a}	12.12 ± 6.41^{a}
Al saturation (%)	22.17 ± 19.44^{a}	20.37 ± 3.84^{a}	29.40 ± 1.31^{a}
Texture	Silty clay, loam	Loam	Sandy clay loam

Note: Classification used the threshold value prescribed by Center for Soil and Agro-Climate Research (1983).

understorey and sapling vegetations between the reclaimed sites and the premining areas with only 20% similarity (Hapsari et al., 2020). Furthermore, the recolonized terrestrial plants in the reclamation sites had a large portion of exotic species with some of them were considered as invasive (Hapsari et al, 2020).

On the other hand, the results of the vegetation analysis of recolonization of epiphytic plants demonstrated that the reclaimed sites seemed more habitable for these plants since there was a number of epiphytic plants grew on the pioneer trees (Figure 3 and Table 3). In particular there were three species of epiphytic orchid attached on the host trees. However, the species and abundance of the orchids in the reclaimed site are different with the orchids that grow in primary forest in East Kalimantan (Trimanto & Sofiah, 2018). Epiphytic plants have an important role in forest ecology because they can be used as bioindicators of the conditions of abiotic factors and climate change (Zotz & Bader, 2009). In primary forests with healthy ecosystems, epiphytes are more diverse than in disturbed forests, since the presence of epiphytes is related with tree diversity (Barthlott et al., 2001).

Combining the natural regeneration in both terrestrial and epiphytic plants suggest that the succession in the reclaimed sites had been progressing, with particular favour on the upperground habitats. However, the succession trajectory was still far away to resemble the vegetation conditions as at the premining areas. Therefore, several management interventions, including enrichment planting of native trees, are necessary to accelerate the recovery of biodiversity elements of the vegetation. Such intervention is now increasingly advocated in mining sectors (Doley et al., 2012; Swab et al., 2017) although there has been limited empirical evidence to support such premise, especially in the context of tropical landscape.

Our study provided evidence that the enrichment planting of native plant species into postmining reclamation site had high rates of survival and growth in term of diameter and height (Tables 5, 6 and 7). During six months of observation, 97% of the planted native plants were survived with average increments in diameter and height of 0.28 cm and 19.24 cm, respectively. Yet, we acknowledge that six months period is a relatively short period of observation and a longer temporal monitoring timeline is required to see the performance of survival and growth of the enrichment planting of native species. In particular interest, the planted native plant species from Dipterocarpaceae family were well adapted. Similar finding was also revealed by Lestari et. al, (2019) in which several native plants from Dipterocarpaceae family could adapt well in a post coal mining reclamation area in East Kalimantan although the presence of inundated water and soil acidity became the limiting factors. In our study, we noted no inundated water at the observation plot with soil pH value ranged from 4.66–4.75 and 4.32–4.51 at the 9-year-old and the 17-year-old reclaimed sites, respectively although the acidity of the soil in both sites is not different. The high acidity of the soil in both reclamation sites with pH < 5 was due to oxidation of residual elements of coal particularly iron sulphide. The planted native plant species will add the biodiversity value of the reclaimed sites, since we found only limited number of native plant species that grew spontaneously on the reclamation sites.

While the indicators of natural regeneration at the reclaimed sites were poorer than those at the premining sites, surprisingly the above-ground carbon storage at the two reclamation sites were higher, up to six times larger, than that at the premining site (Table 8). The estimated value of carbon stock of pioneer trees in reclamation area was 90.42 ton/ha at the 9-year-old reclaimed site and 129.58 ton/ha at the 17-year-old, it is equivalent to a regenerating forest. When compared with carbon stored in lowland primary forest in Kalimantan (Krisnawati et al., 2014), the carbon stock in the 17-year-old reclamation site is approximately half of that in the primary forest. If the process of forest succession in the reclamation area continues, the carbon stock is expected to increase.

The high carbon storage in the reclaimed sites is due to the intensive planting of fast-growing pioneer trees, such as *Albizia saman* and *Senna siamea*, while on the contrary at the premining sites there were only few trees remained, mostly in small and medium sizes, since the landscapes were in degraded condition caused by logging and fires. While storing carbon in the form of tree biomass, the planting of pioneer trees also helped to improve the micro-climate conditions, mainly due to the increasing canopy cover as indicated by the temperature and sunlight intensity which were lower at the 17-year-old reclaimed site than those at the 9-year-old (Table 9). The occurrence of recolonizing epiphytic plants on the pioneer trees also supported the premise that the micro-climate at the reclaimed site had been enhanced.

Litter fall from the pioneer trees could also improve soil conditions since open-cast mining can cause loss of concentrations of organic carbon, soil nitrogen and change in soil pH to be more acidic (Shrestha & Lal, 2011). The accumulation of C and N in the soil layer is an important factor that determines many other soil biological properties (Frouz et al., 2013). Yet, C/N ratio was still better at the premining sites than that at the reclamation sites in which the C/N ratio greatly determines the presence of soil microbes (Hogberg et al., 2007). There was no significant difference in pH value, C organic and N total between the premining area and the reclamation sites. Edaphic or soil conditions may have a strong effect on vegetation productivity (Foster and Bhatti 2006).

In general, the soils at the reclamation sites were in poor conditions according to the threshold value prescribed by Center for Soil and Agro-Climate Research (1983) (Table 9). It is not surprising since the soil conditions at the premining sites were also poor, which is the characteristic of soils in Kalimantan (Paoli et al., 2006). We found the level of soil macronutrients in the reclamation sites varied. For example, Phosphorus (P) which functions in root and flower development was very low, while Kalium which functions in photosynthesis was very high. Similarly, there was variability in micronutrient contents. A very low content was found in Fe and Mn, while Aluminum (Al) saturation was moderate. This condition is good since the high concentration of Al can be toxic to plants. There was no significant difference in the value of cation exchange capacity (CEC) between the premining site and the reclamation areas. The value of CEC in the both reclamation areas was categorized as low, while the base saturation (BS) value was low at the older reclamation site and medium at the younger reclamation site. These values indicate that the cations available for plants to grow are low. Forest clearing causes a drastic loss of CEC and cations (Zajicova and Chuman 2019), degrading the quality of the soils. The soil degradation in the reclamation site is also confirmed by the fact that Ca and Mg contents were also not significantly different between the three locations. Nonetheless, based on soil texture, the older reclamation site had better soil texture than the younger reclamation site since the sandy soil in the older reclamation site has better porosity for plant root development.

Several studies have shown that soil conditions can be improved through the addition of organic matter (e.g., animal manure, crop residues, and organic waste). Organic compounds can be added into reclamation area to activate the microbial population in the reclaimed soil. Pyrogenic Carbonaceous Material (PCM) and Pig Manure (PM) have been tested to contribute to the improvement of soil structure and stubborn organic matter (C). They also decrease the mobility of metals (Zornoza et al., 2016). Acid soil with low pH value can be overcome by making drainage and adding alkaline materials such as calcite ($CaCO_3$), dolomite [$CaMg(CO_3)_2$], burnt lime (CaO), slag [$CaSiO_3$], and slaked [$Ca(OH)_2$] (Negim 2009). Microbial bio-inoculants can be applied to increase soil fertility and are useful in soil phytoremediation (Khan, 2005; Khalid et al., 2009). The application of microbes in mine site rehabilitation is a cost effective, green and sustainable approach (Thavamani et al., 2017).

In conclusion, our study contributes to a new understanding that using single indicator as a monitoring tool to assess revegetation success in postcoal mining site can be biased. A more comprehensive, yet simple, approach by integrating several measures of floristic conditions as demonstrated in this study would provide a much better assessment on the trajectory of vegetation succession of mine-site reclamation. Also, to our knowledge, this study is the first that observing the occurrence of recolonizing epiphytic plants in postmining reclamation area. Therefore, vegetation analysis of epiphytic plants can be used as an element of monitoring indicators with a simpler application than other indicators. In the context of policy and management implications, our findings suggest that while it is relatively easy to recover the above-ground biomass in postmining reclamation, it is not the case for biodiversity. Therefore, enrichment planting using native plant species is necessary to accelerate the biodiversity recovery of the vegetation in postmining reclamation site. While there are several government regulations that impose the planting of native species on postmined land, our study provides empirical evidence to back up such government measures.

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Author's contribution

All authors contributed equally in this manuscript from conceptualization, fieldworks, writing the manuscript, review and editing of the final manuscript.

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Appendix I

Table 1. Important Value Index (IVI) and Shannon-Wiener diversity index (H') of understorey layer at the 9-year-old reclamation site

No	Species	Family	Ind	F	KR	FR	IVI	H'
1.	*Asplenium nidus*	Aspleniaceae	1	0.08	0.15	0.85	1.00	0.01
2.	*Asystasia gangetica*	Acanthaceae	95	0.46	14.68	5.08	19.77	0.28
3.	*Axonopus compressus*	Poaceae	22	0.38	3.40	4.24	7.64	0.11
4.	*Callicarpa pentandra*	Lamiaceae	5	0.15	0.77	1.69	2.47	0.04
5.	*Canthium glabrum*	Rubiaceae	1	0.08	0.15	0.85	1.00	0.01
6.	*Centrosema pubescens*	Leguminosae	1	0.08	0.15	0.85	1.00	0.01
7.	*Christella dentata*	Thelypteridaceae	5	0.15	0.77	1.69	2.47	0.04
8.	*Chromolaena odorata*	Asteraceae	30	0.46	4.64	5.08	9.72	0.14
9.	*Clidemia hirta*	Melastomataceae	52	0.69	8.04	7.63	15.66	0.20
10.	*Davallia denticulata*	Davalliacea	25	0.08	3.86	0.85	4.71	0.13
11.	*Embelia* sp.	Primulaceae	3	0.23	0.46	2.54	3.01	0.02
12.	*Etlingiera* sp.	Zingiberaceae	3	0.08	0.46	0.85	1.31	0.02
13.	*Glochidion littorale*	Phyllanthaceae	2	0.08	0.31	0.85	1.16	0.02
14.	*Glochidion obscurum*	Phyllanthaceae	6	0.31	0.93	3.39	4.32	0.04
15.	*Homalanthus populneus*	Euphorbiaceae	1	0.08	0.15	0.85	1.00	0.01
16.	*Hyptis capitata*	Lamiaceae	13	0.08	2.01	0.85	2.86	0.08
17.	*Leea angulata*	Vitaceae	7	0.31	1.08	3.39	4.47	0.05
18.	*Lygodium circinatum*	Lygodiaceae	4	0.23	0.62	2.54	3.16	0.03
19.	*Lygodium* sp.	Lygodiaceae	7	0.31	1.08	3.39	4.47	0.05
20.	*Mallotus japonicus*	Euphorbiaceae	5	0.31	0.77	3.39	4.16	0.04
21.	*Melastoma malabathricum*	Melastomataceae	6	0.38	0.93	4.24	5.16	0.04
22.	*Melicope glabra*	Rutaceae	1	0.08	0.15	0.85	1.00	0.01
23.	*Mikania cordifolia*	Asteraceae	10	0.54	1.55	5.93	7.48	0.06
24.	*Mimosa pudica*	Leguminosae	8	0.23	1.24	2.54	3.78	0.05
25.	*Nephrolepis exaltata*	Nephrolepidaceae	6	0.23	0.93	2.54	3.47	0.04
26.	*Oplismenus* sp.	Poaceae	12	0.31	1.85	3.39	5.24	0.07
27.	*Phyllanthus niruri*	Phyllanthaceae	1	0.08	0.15	0.85	1.00	0.01

28.	*Phyllanthus urinaria*	Phyllanthaceae	2	0.08	0.31	0.85	1.16	0.02
29.	*Piper aduncum*	Piperaceae	25	0.62	3.86	6.78	10.64	0.13
30.	*Plagiostachys albiflora*	Zingiberaceae	5	0.08	0.77	0.85	1.62	0.04
31.	*Poaceae*	Poaceae	3	0.08	0.46	0.85	1.31	0.02
32.	*Polytrias indica*	Poaceae	172	0.77	26.58	8.47	35.06	0.35
33.	*Rubus sp.*	Rubiaceae	1	0.08	0.15	0.85	1.00	0.01
34.	*Rungia sp.*	Acanthaceae	15	0.08	2.32	0.85	3.17	0.09
35.	*Scleria scrobiculata*	Cyperaceae	85	0.54	13.14	5.93	19.07	0.27
36.	*Senna siamea*	Leguminosae	2	0.08	0.31	0.85	1.16	0.02
37.	*Smilax gigantea*	Smilacaceae	3	0.15	0.46	1.69	2.16	0.02
38.	*Tetracera scandens*	Dilleniaceae	2	0.08	0.31	0.85	1.16	0.02
			647	9.08	100	100	200	**2.62**
	Evenness index (E)							**0.72**
	Richness index (R)							**5.71**

Table 2. Important Value Index (IVI) and Shannon-Wiener diversity index (H’) of sapling layer at the 9-year-old reclamation site

No	Species	Family	Ind	F	KR	FR	IVI	H’
1.	*Acacia mangium*	Leguminosae	2	0.15	2.47	3.77	6.24	0.09
2.	*Allophylus cobbe*	Sapindaceae	1	0.08	1.23	1.89	3.12	0.05
3.	*Blumeodendron tokbrai*	Euphorbiaceae	1	0.08	1.23	1.89	3.12	0.05
4.	*Callicarpa longifolia*	Lamiaceae	4	0.31	4.94	7.55	12.49	0.15
5.	*Canthium glabrum*	Rubiaceae	1	0.08	1.23	1.89	3.12	0.05
6.	*Senna siamea*	Leguminosae	9	0.31	11.11	7.55	18.66	0.24
7.	*Clerodendrum laevifolium*	Lamiacaeae	2	0.08	2.47	1.89	4.36	0.09
8.	*Cratoxylum sumatranum*	Hypericaceae	1	0.08	1.23	1.89	3.12	0.05
9.	*Glochidion littorale*	Phyllanthaceae	5	0.38	6.17	9.43	15.61	0.17
10.	*Glochidion obscurum*	Phyllanthaceae	10	0.46	12.35	11.32	23.67	0.26
11.	*Guioa pleuropteris*	Sapindaceae	5	0.38	6.17	9.43	15.61	0.17
12.	*Homalanthus populneus*	Euphorbiaceae	1	0.08	1.23	1.89	3.12	0.05
13.	*Leea angulata*	Vitaceae	4	0.15	4.94	3.77	8.71	0.15
14.	*Mallotus japonicus*	Euphorbiaceae	9	0.23	11.11	5.66	16.77	0.24

15.	*Melastoma malabathricum*	Melastomataceae	11	0.38	13.58	9.43	23.01	0.27
16.	*Melicope glabra*	Rutaceae	1	0.08	1.23	1.89	3.12	0.05
17.	*Piper aduncum*	Piperaceae	6	0.31	7.41	7.55	14.95	0.19
18.	*Pternandra galeata*	Melastomataceae	1	0.08	1.23	1.89	3.12	0.05
19.	*Semecarpus* sp.	Anacardiaceae	5	0.23	6.17	5.66	11.83	0.17
20.	*Vitex pinnata*	Lamiaceae	2	0.15	2.47	3.77	6.24	0.09
			81	4.08	100	100	200	**2.68**
	Evenness index (E)							**0.89**
	Richness index (R)							**4.32**

Table 3. Important Value Index (IVI) and Shannon-Wiener diversity index (H') of understorey layer at the 17-year-old reclamation site

No	Species	Family	Ind	F	KR	FR	IVI	H'
1.	*Acacia mangium*	Leguminosae	2	0.08	0.31	0.82	1.13	0.02
2.	*Alocasia princeps*	Araceae	5	0.15	0.76	1.64	2.40	0.04
3.	*Alpinia* sp.	Zingiberaceae	2	0.08	0.31	0.82	1.13	0.02
4.	*Asplenium nidus*	Aspleniaceae	1	0.08	0.15	0.82	0.97	0.01
5.	*Asystasia gangetica*	Acanthaceae	261	0.77	39.85	8.20	48.04	0.37
6.	*Axonopus compressus*	Poaceae	18	0.31	2.75	3.28	6.03	0.10
7.	*Blumea lacera*	Asteraceae	1	0.08	0.15	0.82	0.97	0.01
8.	*Callicarpa longifolia*	Lamiaceae	26	0.69	3.97	7.38	11.35	0.13
9.	*Canthium glabrum*	Rubiaceae	32	0.31	4.89	3.28	8.16	0.15
10.	*Chromolaena odorata*	Asteraceae	23	0.38	3.51	4.10	7.61	0.12
11.	*Clausena* sp.	Rutaceae	6	0.31	0.92	3.28	4.19	0.04
12.	*Clidemia hirta*	Melastomataceae	4	0.23	0.61	2.46	3.07	0.03
13.	*Cratoxylum sumatranum*	Hypericaceae	1	0.08	0.15	0.82	0.97	0.01
14.	*Curculigo orchioides*	Hypoxidaceae	3	0.08	0.46	0.82	1.28	0.02
15.	*Embelia ribes*	Primulaceae	5	0.31	0.76	3.28	4.04	0.04
16.	*Ficus septica*	Moraceae	1	0.08	0.15	0.82	0.97	0.01
17.	*Glochidion obscurum*	Phyllanthaceae	5	0.23	0.76	2.46	3.22	0.04
18.	*Guioa pleuropteris*	Sapindaceae	1	0.08	0.15	0.82	0.97	0.01
19.	*Gymnema* sp.	Apocynaceae	1	0.08	0.15	0.82	0.97	0.01
20.	*Imperata cylindrica*	Poaceae	1	0.08	0.15	0.82	0.97	0.01
21.	*Leea angulata*	Vitaceae	9	0.31	1.37	3.28	4.65	0.06

22.	*Leucaena leucocephala*	Leguminosae	1	0.08	0.15	0.82	0.97	0.01
23.	*Lygodium circinatum*	Lygodiaceae	12	0.38	1.83	4.10	5.93	0.07
24.	*Macaranga gigantea*	Euphorbiaceae	2	0.15	0.31	1.64	1.94	0.02
25.	*Mallotus japonicus*	Euphorbiaceae	3	0.23	0.46	2.46	2.92	0.02
26.	*Melastoma malabathricum*	Melastomataceae	13	0.31	1.98	3.28	5.26	0.08
27.	*Melicope glabra*	Rutaceae	5	0.31	0.76	3.28	4.04	0.04
28.	*Mikania cordifolia*	Asteraceae	9	0.23	1.37	2.46	3.83	0.06
29.	*Nephrolepis exaltata*	Nephrolepidaceae	19	0.31	2.90	3.28	6.18	0.10
30.	*Oplismenus burmannii*	Poaceae	3	0.08	0.46	0.82	1.28	0.02
31.	*Oplismenus* sp.	Poaceae	7	0.15	1.07	1.64	2.71	0.05
32.	*Passiflora* sp.	Passifloraceae	4	0.23	0.61	2.46	3.07	0.03
33.	*Phyllanthus urinaria*	Phyllanthaceae	7	0.23	1.07	2.46	3.53	0.05
34.	*Piper aduncum*	Piperaceae	4	0.15	0.61	1.64	2.25	0.03
35.	*Polytrias indica*	Poaceae	84	0.69	12.82	7.38	20.20	0.26
36.	*Scleria scrobiculata*	Cyperaceae	46	0.38	7.02	4.10	11.12	0.19
37.	*Solanum* sp.	Solanaceae	8	0.23	1.22	2.46	3.68	0.05
38.	*Tetracera scandens*	Dilleniaceae	12	0.15	1.83	1.64	3.47	0.07
39.	*Urena lobata*	Malvaceae	5	0.08	0.76	0.82	1.58	0.04
40.	*Uvaria* sp.	Annonaceae	3	0.23	0.46	2.46	2.92	0.02
			655	9.38	100	100	200	**2.46**
	Evenness index (E)							**0.68**
	Richness index (R)							**5.71**

Table 4. Important Value Index (IVI) and Shannon-Wiener diversity index (H') of sapling layer at the 17-year-old reclamation site

No	Species	Family	Ind	F	KR	FR	IVI	H'
1.	*Beilschmiedia* sp.	Lauraceae	1	0.08	0.83	1.49	2.33	0.04
2.	*Bridelia stipularis*	Phyllanthaceae	1	0.08	0.83	1.49	2.33	0.04
3.	*Callicarpa longifolia*	Lamiaceae	19	0.62	15.83	11.94	27.77	0.29
4.	*Canthium glabrum*	Rubiaceae	15	0.62	12.50	11.94	24.44	0.26
5.	*Clausena* sp.	Rutaceae	4	0.23	3.33	4.48	7.81	0.11
6.	*Dracontomelon dao*	Anacardiaceae	1	0.08	0.83	1.49	2.33	0.04

7.	*Eoudia* sp.	Rutaceae	2	0.08	1.67	1.49	3.16	0.07
8.	*Glochidion littorale*	Phyllanthaceae	1	0.08	0.83	1.49	2.33	0.04
9.	*Glochidion obscurum*	Phyllanthaceae	4	0.31	3.33	5.97	9.30	0.11
10.	*Guioa pleuropteris*	Sapindaceae	3	0.15	2.50	2.99	5.49	0.09
11.	*Homalanthus populneus*	Euphorbiaceae	4	0.15	3.33	2.99	6.32	0.11
12.	*Leea angulata*	Vitaceae	5	0.23	4.17	4.48	8.64	0.13
13.	*Maasia glauca*	Annonaceae	1	0.08	0.83	1.49	2.33	0.04
14.	*Macaranga gigantea*	Euphorbiaceae	6	0.23	5.00	4.48	9.48	0.15
15.	*Macaranga tanarius*	Euphorbiaceae	21	0.77	17.50	14.93	32.43	0.31
16.	*Macaranga triloba*	Euphorbiaceae	2	0.15	1.67	2.99	4.65	0.07
17.	*Mallotus japonicus*	Euphorbiaceae	8	0.46	6.67	8.96	15.62	0.18
18.	*Melastoma malabathricum*	Melastomataceae	17	0.31	14.17	5.97	20.14	0.28
19.	*Piper aduncum*	Piperaceae	1	0.08	0.83	1.49	2.33	0.04
20.	*Pternandra galeata*	Melastomaceae	1	0.08	0.83	1.49	2.33	0.04
21.	*Schefflera elliptica*	Araliaceae	1	0.08	0.83	1.49	2.33	0.04
22.	*Senna siamea*	Caesalpiniaceae	1	0.08	0.83	1.49	2.33	0.04
23.	*Vernonia arborea*	Asteraceae	1	0.15	0.83	2.99	3.82	0.04
			120	5.15	100	100	200	**2.56**
	Evenness index (E)							**0.86**
	Richness index (R)							**3.97**

Table 5. Important Value Index (IVI) and Shannon-Wiener diversity index (H') of understorey layer at the pre-mining areas

No	Species	Family	Ind	F	KR	FR	IVI	H'
1.	*Alocasia princeps*	Araceae	1	0.04	0.13	0.37	0.50	0.01
2.	*Alpinia* sp.	Zingiberaceae	13	0.24	1.69	2.20	3.89	0.07
3.	*Archidendron havilandii*	Leguminosae	4	0.04	0.52	0.37	0.89	0.03
4.	*Artocarpus tamaran*	Moraceae	1	0.04	0.13	0.37	0.50	0.01
5.	*Asplenium polyodon*	Aspleniaceae	1	0.04	0.13	0.37	0.50	0.01
6.	*Bauhinia binnata*	Leguminosae	7	0.08	0.91	0.73	1.64	0.04
7.	*Bignoniaceae*	Bignoniaceae	6	0.04	0.78	0.37	1.15	0.04
8.	*Caesalpinia* sp.	Leguminosae	1	0.04	0.13	0.37	0.50	0.01
9.	*Calathea zebrina*	Marantaceae	8	0.12	1.04	1.10	2.14	0.05
10.	*Callicarpa longifolia*	Lamiaceae	1	0.04	0.13	0.37	0.50	0.01

11.	*Calopogonium mucunoides*	Leguminosae	1	0.04	0.13	0.37	0.50	0.01
12.	*Canthium glabrum*	Rubiaceae	20	0.36	2.60	3.30	5.89	0.09
13.	*Christella* sp.	Thelyptridaceae	16	0.16	2.08	1.47	3.54	0.08
14.	*Clausena* sp.	Rutaceae	3	0.12	0.39	1.10	1.49	0.02
15.	*Clerodendrum laevifolium*	Lamiaceae	2	0.04	0.26	0.37	0.63	0.02
16.	*Clerodendrum* sp.	Lamiaceae	3	0.08	0.39	0.73	1.12	0.02
17.	*Clidemia hirta*	Melastomataceae	8	0.04	1.04	0.37	1.41	0.05
18.	*Commelina* sp.	Commelinaceae	4	0.08	0.52	0.73	1.25	0.03
19.	*Costus spiralis*	Costaceae	1	0.04	0.13	0.37	0.50	0.01
20.	*Cratoxylum sumatranum*	Hypericaceae	1	0.04	0.13	0.37	0.50	0.01
21.	*Croton argyratus*	Euphorbiaceae	2	0.08	0.26	0.73	0.99	0.02
22.	*Croton* sp.	Euphorbiaceae	19	0.24	2.47	2.20	4.67	0.09
23.	*Croton* sp2.	Euphorbiaceae	5	0.04	0.65	0.37	1.02	0.03
24.	*Cryptocarya* sp.	Lauraceae	2	0.04	0.26	0.37	0.63	0.02
25.	*Ctenanthe setosa*	Marantaceae	10	0.32	1.30	2.93	4.23	0.06
26.	*Cucurbita* sp.	Cucurbitaceae	2	0.08	0.26	0.73	0.99	0.02
27.	*Curculigo orchioides*	Hypoxidaceae	14	0.24	1.82	2.20	4.02	0.07
28.	*Cyperaceae*	Cyperaceae	21	0.32	2.73	2.93	5.66	0.10
29.	*Dacryodes costata*	Burseraceae	1	0.04	0.13	0.37	0.50	0.01
30.	*Dacryodes rostrata*	Burseraceae	1	0.04	0.13	0.37	0.50	0.01
31.	*Debregeasia* sp.	Urticaceae	2	0.08	0.26	0.73	0.99	0.02
32.	*Derris elliptica*	Leguminosae	24	0.44	3.12	4.03	7.15	0.11
33.	*Derris* sp.	Leguminosae	7	0.08	0.91	0.73	1.64	0.04
34.	*Dillenia excelsa*	Dilleniaceae	5	0.16	0.65	1.47	2.11	0.03
35.	*Dioscorea alata*	Dioscoreaceae	1	0.04	0.13	0.37	0.50	0.01
36.	*Diospyros* sp.	Ebenaceae	3	0.08	0.39	0.73	1.12	0.02
37.	*Donax canniformis*	Marantaceae	49	0.16	6.36	1.47	7.83	0.18
38.	*Embelia ribes*	Primulaceae	1	0.04	0.13	0.37	0.50	0.01
39.	*Etlingera* sp.	Zingiberaceae	4	0.04	0.52	0.37	0.89	0.03
40.	*Fagara* sp.	Rutaceae	7	0.04	0.91	0.37	1.28	0.04
41.	*Ficus callosa*	Moraceae	1	0.04	0.13	0.37	0.50	0.01
42.	*Ficus septica*	Moraceae	2	0.08	0.26	0.73	0.99	0.02
43.	*Ficus sp.*	Moraceae	35	0.04	4.55	0.37	4.91	0.14
44.	*Flagellaria indica*	Flagellariaceae	1	0.04	0.13	0.37	0.50	0.01
45.	*Gardenia* sp.	Rubiaceae	2	0.08	0.26	0.73	0.99	0.02
46.	*Glochidion littorale*	Phyllanthaceaee	1	0.04	0.13	0.37	0.50	0.01
47.	*Glochidion* sp.	Phyllanthaceaee	4	0.12	0.52	1.10	1.62	0.03
48.	*Gonocaryum litorale*	Cardiopteridaceae	1	0.04	0.13	0.37	0.50	0.01

49.	*Gymnema* sp.	Apocynaceae	2	0.04	0.26	0.37	0.63	0.02
50.	*Homalanthus populneus*	Euphorbiaceae	2	0.04	0.26	0.37	0.63	0.02
51.	*Hyptis capitata*	Lamiaceae	9	0.08	1.17	0.73	1.90	0.05
52.	*Icacinaceae*	Icacinaceae	1	0.04	0.13	0.37	0.50	0.01
53.	*Irvingia malayana*	Irvingiaceae	1	0.04	0.13	0.37	0.50	0.01
54.	*Koordersiodendron pinnatum*	Anacardiacae	1	0.04	0.13	0.37	0.50	0.01
55.	*Korthalsia* sp.	Arecaceae	9	0.08	1.17	0.73	1.90	0.05
56.	*Korthalsia* sp2.	Arecaceae	1	0.04	0.13	0.37	0.50	0.01
57.	*Leea angulata*	Vitaceae	28	0.48	3.64	4.40	8.03	0.12
58.	*Lepisanthes amoena*	Sapindaceae	6	0.12	0.78	1.10	1.88	0.04
59.	*Lygodium circinatum*	Lygodiaceae	45	0.56	5.84	5.13	10.97	0.17
60.	*Lygodium* sp.	Lygodiaceae	2	0.08	0.26	0.73	0.99	0.02
61.	*Maasia glauca*	Annonaceae	6	0.04	0.78	0.37	1.15	0.04
62.	*Macaranga tanarius*	Euphorbiaceae	4	0.08	0.52	0.73	1.25	0.03
63.	*Macaranga triloba*	Euphorbiaceae	4	0.08	0.52	0.73	1.25	0.03
64.	*Mallotus japonicus*	Euphorbiaceae	2	0.04	0.26	0.37	0.63	0.02
65.	*Mallotus* sp.	Euphorbiaceae	9	0.16	1.17	1.47	2.63	0.05
66.	*Mallotus* sp.2	Euphorbiaceae	4	0.12	0.52	1.10	1.62	0.03
67.	*Mapania cuspidata*	Cyperaceae	1	0.04	0.13	0.37	0.50	0.01
68.	*Melastoma malabathricum*	Melastomataceae	3	0.04	0.39	0.37	0.76	0.02
69.	*Mezzettia* sp.	Annonaceae	3	0.08	0.39	0.73	1.12	0.02
70.	*Mikania cordifolia*	Asteraceae	11	0.2	1.43	1.83	3.26	0.06
71.	*Mucuna* sp.	Leguminosae	6	0.04	0.78	0.37	1.15	0.04
72.	*Mussaenda frondosa*	Rubiaceae	9	0.16	1.17	1.47	2.63	0.05
73.	*Nephrolepis exaltata*	Nephrolepidaceae	43	0.24	5.58	2.20	7.78	0.16
74.	*Oldenlandia hedyotidea*	Rubiaceae	5	0.08	0.65	0.73	1.38	0.03
75.	*Oplismenus burmanni*	Poaceae	16	0.2	2.08	1.83	3.91	0.08
76.	*Orophea enneandra*	Annonaceae	5	0.08	0.65	0.73	1.38	0.03
77.	*Paederia foetida*	Rubiaceae	3	0.04	0.39	0.37	0.76	0.02
78.	*Pandanus* sp.	Pandanaceae	6	0.12	0.78	1.10	1.88	0.04
79.	*Papilionaceae*	Papilionaceae	1	0.04	0.13	0.37	0.50	0.01
80.	*Piper aduncum*	Piperaceae	8	0.16	1.04	1.47	2.50	0.05
81.	*Piper* sp.	Piperaceae	5	0.04	0.65	0.37	1.02	0.03

82.	*Pisonia* sp.	Nyctaginceaeae	2	0.08	0.26	0.73	0.99	0.02
83.	*Poaceae*	Poaceae	5	0.04	0.65	0.37	1.02	0.03
84.	*Poikilospermum* sp.	Urticaceae	1	0.04	0.13	0.37	0.50	0.01
85.	*Polytrias indica*	Poaceae	20	0.08	2.60	0.73	3.33	0.09
86.	*Pteris* sp.	Pteridaceae	6	0.08	0.78	0.73	1.51	0.04
87.	*Pternandra galeata*	Melastomaceae	7	0.16	0.91	1.47	2.37	0.04
88.	*Rubus* sp.	Rosaceae	1	0.04	0.13	0.37	0.50	0.01
89.	*Rubus* sp1.	Rosaceae	1	0.04	0.13	0.37	0.50	0.01
90.	*Rubus fraxinifolius*	Rosaceae	1	0.04	0.13	0.37	0.50	0.01
91.	*Saurauia* sp.	Actinidiaceae	11	0.08	1.43	0.73	2.16	0.06
92.	*Sauropus androgynus*	Phyllanthaceae	3	0.04	0.39	0.37	0.76	0.02
93.	*Schizostachyum* sp.	Poaceae	3	0.04	0.39	0.37	0.76	0.02
94.	*Scindapsus* sp.	Araceae	5	0.04	0.65	0.37	1.02	0.03
95.	*Scleria scrobiculata*	Cyperaceae	22	0.28	2.86	2.56	5.42	0.10
96.	*Selaginella plana*	Selaginellaceae	1	0.04	0.13	0.37	0.50	0.01
97.	*Smilax gigantea*	Smilacaceae	23	0.24	2.99	2.20	5.18	0.10
98.	*Strobilanthus* sp.	Acanthaceae	2	0.04	0.26	0.37	0.63	0.02
99.	*Syzygium* sp.	Myrtaceae	3	0.08	0.39	0.73	1.12	0.02
100.	*Syzygium* sp2.	Myrtaceae	3	0.04	0.39	0.37	0.76	0.02
101.	*Tetracera scandens*	Dilleniaceae	6	0.2	0.78	1.83	2.61	0.04
102.	*Tetrastigma* sp.	Vitaceae	3	0.08	0.39	0.73	1.12	0.02
103.	*Uncaria* sp.	Rubiaceae	1	0.04	0.13	0.37	0.50	0.01
104.	*Uvaria* sp.	Annonaceae	13	0.24	1.69	2.20	3.89	0.07
105.	*Xanthophyllum* sp.	Polygalaceae	2	0.04	0.26	0.37	0.63	0.02
106.	Zingiber sp.	Zingibaceae	35	0.28	4.55	2.56	7.11	0.14
			770	10.92	100	100	200	**4.05**
	Evenness index (E)							**0.87**
	Richness index (R)							**15.80**

Table 6. Important Value Index (IVI) and Shannon-Wiener diversity index (H') of sapling layer at the pre-mining areas

No	Species	Family	Ind	F	KR	FR	IVI	H'
1.	*Abelmoschus* sp.	Malvaceae	1	0.04	0.26	0.45	0.72	0.02
2.	*Actinodaphne glabra*	Lauraceae	1	0.04	0.26	0.45	0.72	0.02
3.	*Actinodaphne* sp.	Lauraceae	1	0.04	0.26	0.45	0.72	0.02
4.	*Aglaia* sp.	Meliaceae	1	0.04	0.26	0.45	0.72	0.02
5.	*Antidesma* sp.	Euphorbiaceae	1	0.04	0.26	0.45	0.72	0.02
6.	*Archidendron havilandii*	Leguminosae	1	0.04	0.26	0.45	0.72	0.02
7.	*Artocarpus altilis*	Moraceae	1	0.04	0.26	0.45	0.72	0.02

8.	*Baccaurea tetrandra*	Phyllanthaceaee	2	0.08	0.52	0.91	1.43	0.03
9.	*Bridelia* sp.	Phyllanthaceaee	1	0.04	0.26	0.45	0.72	0.02
10.	*Callicarpa longifolia*	Lamiaceae	5	0.12	1.31	1.36	2.68	0.06
11.	*Callicarpa sp*	Lamiaceae	2	0.08	0.52	0.91	1.43	0.03
12.	*Cananga odorata*	Annonaceae	1	0.04	0.26	0.45	0.72	0.02
13.	*Canarium asperum*	Burseraceae	1	0.04	0.26	0.45	0.72	0.02
14.	*Canthium glabrum*	Rubiaceae	10	0.12	2.62	1.36	3.99	0.10
15.	*Clerodendrum laevifolium*	Lamiaceae	4	0.04	1.05	0.45	1.50	0.05
16.	*Clerodendrum* sp.	Lamiaceae	49	0.52	12.86	5.91	18.77	0.26
17.	*Cratoxylum sumatranum*	Hypericaceae	3	0.12	0.79	1.36	2.15	0.04
18.	*Croton argyratus*	Euphorbiaceae	2	0.04	0.52	0.45	0.98	0.03
19.	*Croton* sp.	Euphorbiaceae	15	0.36	3.94	4.09	8.03	0.13
20.	*Cryptocarya* sp.	Lauraceae	3	0.12	0.79	1.36	2.15	0.04
21.	*Crysobalanaceae*	Crysobalanaceae	1	0.04	0.26	0.45	0.72	0.02
22.	*Dacryodes costata*	Burseraceae	3	0.08	0.79	0.91	1.70	0.04
23.	*Dacryodes rostrata*	Burseraceae	1	0.04	0.26	0.45	0.72	0.02
24.	*Dacryodes* sp.	Burseraceae	1	0.04	0.26	0.45	0.72	0.02
25.	*Debregeasia* sp.	Urticaceae	2	0.04	0.52	0.45	0.98	0.03
26.	*Dillenia excelsa*	Dilleniaceae	16	0.24	4.20	2.73	6.93	0.13
27.	*Dillenia reticulata*	Dilleniaceae	2	0.08	0.52	0.91	1.43	0.03
28.	*Dimocarpus* sp.	Sapindaceae	1	0.04	0.26	0.45	0.72	0.02
29.	*Diospyros* sp.	Ebenaceae	3	0.12	0.79	1.36	2.15	0.04
30.	*Eusideroxylon zwageri*	Lauraceae	5	0.08	1.31	0.91	2.22	0.06
31.	*Ficus callosa*	Moraceae	3	0.08	0.79	0.91	1.70	0.04
32.	*Ficus geocarpa*	Moraceae	15	0.44	3.94	5.00	8.94	0.13
33.	*Ficus septica*	Moraceae	8	0.16	2.10	1.82	3.92	0.08
34.	*Ficus variegata*	Moraceae	1	0.04	0.26	0.45	0.72	0.02
35.	*Garcinia* sp.	Clusiaceae	2	0.08	0.52	0.91	1.43	0.03
36.	*Gardenia* sp.	Rubiaceae	5	0.08	1.31	0.91	2.22	0.06
37.	*Glochidion littorale*	Phyllanthaceaee	3	0.12	0.79	1.36	2.15	0.04
38.	*Glochidion obscurum*	Phyllanthaceaee	6	0.16	1.57	1.82	3.39	0.07
39.	*Glochidion* sp.	Phyllanthaceaee	5	0.2	1.31	2.27	3.59	0.06
40.	*Gluta* sp.	Anacardiaceae	3	0.08	0.79	0.91	1.70	0.04
41.	*Homalanthus populneus*	Euphorbiaceae	18	0.48	4.72	5.45	10.18	0.14
42.	*Knema* sp.	Myristicaceae	1	0.04	0.26	0.45	0.72	0.02

43.	*Koordersiodendron pinnatum*	Anacardiaceae	6	0.12	1.57	1.36	2.94	0.07
44.	*Leea angulata*	Vitaceae	25	0.56	6.56	6.36	12.93	0.18
45.	*Lepisanthes amoena*	Sapindaceae	5	0.12	1.31	1.36	2.68	0.06
46.	*Litsea* sp.	Lauraceae	3	0.12	0.79	1.36	2.15	0.04
47.	*Maasia glauca*	Annonaceae	6	0.16	1.57	1.82	3.39	0.07
48.	*Macaranga gigantea*	Euphorbiaceae	2	0.08	0.52	0.91	1.43	0.03
49.	*Macaranga tanarius*	Euphorbiaceae	24	0.4	6.30	4.55	10.84	0.17
50.	*Mallotus japonicus*	Euphorbiaceae	11	0.16	2.89	1.82	4.71	0.10
51.	*Mallotus* sp.	Euphorbiaceae	2	0.08	0.52	0.91	1.43	0.03
52.	*Melastoma malabathricum*	Melastomataceae	1	0.04	0.26	0.45	0.72	0.02
53.	*Mezzettia* sp.	Annonaceae	2	0.08	0.52	0.91	1.43	0.03
54.	*Miliusa horsfieldii*	Annonaceae	5	0.12	1.31	1.36	2.68	0.06
55.	*Myrsinaceae*	Myrsinaceae	3	0.08	0.79	0.91	1.70	0.04
56.	*Nauclea* sp.	Rubiaceae	4	0.16	1.05	1.82	2.87	0.05
57.	*Orophea enneandra*	Annonaceae	7	0.2	1.84	2.27	4.11	0.07
58.	*Pimelodendron* sp.	Euphorbiaceae	2	0.08	0.52	0.91	1.43	0.03
59.	*Piper aduncum*	Piperaceae	1	0.04	0.26	0.45	0.72	0.02
60.	*Pisonia* sp.	Nyctaginaceae	2	0.04	0.52	0.45	0.98	0.03
61.	*Pternandra galeata*	Melastomataceae	4	0.16	1.05	1.82	2.87	0.05
62.	*Saurauia* sp.	Actinidiaceae	18	0.32	4.72	3.64	8.36	0.14
63.	*Semecarpus* sp.	Anacardiaceae	1	0.04	0.26	0.45	0.72	0.02
64.	*Shorea* sp.	Dipterocarpaceae	2	0.04	0.52	0.45	0.98	0.03
65.	*Sterculia* sp.	Malvaceae	1	0.04	0.26	0.45	0.72	0.02
66.	*Swartzia pinnata*	Leguminosae	12	0.2	3.15	2.27	5.42	0.11
67.	*Syzygium* sp1.	Myrtaceae	3	0.04	0.79	0.45	1.24	0.04
68.	*Syzygium* sp2.	Myrtaceae	8	0.24	2.10	2.73	4.83	0.08
69.	*Tabernaemontana divaricata*	Apocynaceae	2	0.08	0.52	0.91	1.43	0.03
70.	*Trema tomentosa*	Cannabaceae	3	0.12	0.79	1.36	2.15	0.04
71.	*Uncaria acida*	Rubiaceae	1	0.04	0.26	0.45	0.72	0.02
72.	*Uncaria* sp1.	Rubiaceae	4	0.04	1.05	0.45	1.50	0.05
73.	*Uncaria* sp2.	Rubiaceae	1	0.04	0.26	0.45	0.72	0.02
			381	8.8	100	100	200	**3.69**
	Evenness index (E)							**0.86**
	Richness index (R)							**12.12**

*Notes: Ind=number of individual, F= frequency, KR= relative density, FR= relative frequency, IVI= importance value index, H'= diversity index

Appendix 2

Table 1. The survival and growth rate of the inserted native species in the reclamation site.

No	Species	Family	D1	D2	AD	H1	H2	AH
1.	*Actinodaphne glabra*	Lauraceae	2.23	2.39	0.16	66	69	3.00
2.	*Aglaia* sp.	Meliaceae	1.24	1.47	0.23	104	114	10.00
3.	*Alphonsea* sp.	Annonaceae	1.15	1.15	0.00	73	96	23.00
4.	*Aquilaria malaccensis*	Thymelaeaceae	1.05	1.27	0.22	112	142	30.00
5.	*Artabotrys* sp.	Annonaceae	0.83	1.11	0.29	100	211	111.00
6.	*Baccaurea* sp.	Phyllanthaceae	1.43	1.59	0.16	100	107	7.00
7.	*Baccaurea tetrandra*	Phyllanthaceae	1.32	1.59	0.27	98.5	94.5	-4.00
8.	*Bischofia javanica*	Phyllanthaceae	2.26	2.42	0.16	156	181.5	25.50
9.	*Bridelia stipularis*	Phyllanthaceae	1.02	1.43	0.41	139	187	48.00
10.	*Canthium glabrum*	Rubiaceae	1.53	1.85	0.32	171	181.88	10.88
11.	*Carallia brachiata*	Rhizophoraceae	3.60	4.30	0.70	310	445	135.00
12.	*Cleistanthus acuminatus*	Phyllanthaceae	1.91	2.49	0.58	200	263.33	63.33
13.	*Cleistanthus* sp.	Euphorbiaceae	1.34	1.59	0.25	150	94	-56.00
14.	*Clerodendrum laevifolium*	Verbenaceae	1.21	1.31	0.10	127	127	0.00
15.	*Croton* sp.	Euphorbiaceae	1.82	2.23	0.41	183.5	206	22.50
16.	*Dacryodes* sp.	Burseraceae	1.27	1.27	0.00	100	101	1.00
17.	*Dillenia excelsa*	Dilleniaceae	1.80	1.94	0.14	157.08	150.95	-6.13
18.	*Diospyros buxifolia*	Ebenaceae	1.05	1.31	0.25	125	137	12.00
19.	*Diospyros* sp.	Ebenaceae	0.96	1.15	0.19	80	69	-11.00
20.	*Dracontomelon dao*	Anacardiaceae	2.77	3.08	0.31	159	173.5	14.50
21.	*Dryobalanops lanceolata*	Dipterocarpaceae	2.07	2.37	0.30	223.5	278	54.50
22.	*Dryobalanops* sp.	Dipterocarpaceae	2.07	2.39	0.32	223.5	241	17.50
23.	*Melicope glabra*	Rutaceae	2.18	2.36	0.18	212.5	253.5	41.00
24.	*Ficus callosa*	Moraceae	1.86	2.23	0.37	166.5	180	13.50
25.	*Ficus geocarpa*	Moraceae	1.18	2.07	0.89	155	247.5	92.50
26.	*Ficus septica*	Moraceae	1.34	1.53	0.19	178	211	33.00

27.	*Ficus* sp.	Moraceae	1.75	2.40	0.65	85	234.25	149.25
28.								
29.	*Glochidion obscurum*	Phyllanthaceae	2.07	3.11	1.04	263.5	359	95.50
30.	*Guioa pleuropteris*	Sapindaceae	1.91	2.39	0.48	329	403	74.00
31.	*Guioa* sp.	Sapindaceae	1.90	2.28	0.38	237.33	290.17	52.83
32.	*Leea angulata*	Vitaceae	2.07	2.23	0.16	170	176	6.00
33.	*Macaranga tanarius*	Euphorbiaceae	1.74	2.07	0.33	164.92	175.58	10.65
34.	*Mezzettia* sp.	Annonaceae	1.31	1.60	0.29	102.38	131.06	28.69
35.	*Mussaenda frondosa*	Rubiaceae	1.69	1.99	0.30	100	169.5	69.50
36.	*Planchonia valida*	Lecythidaceae	2.55	2.87	0.32	237	245	8.00
37.	*Dracaena* sp.	Dracaenaceae	1.91	1.91	0.00	94.5	96.5	2.00
38.	*Psychotria elata*	Rubiaceae	1.53	1.62	0.10	98.5	110	11.50
39.	*Pterospermum javanicum*	Malvaceae	1.82	2.04	0.23	199	202	3.00
40.	*Miliusa horsfieldii*	Annonaceae	1.66	1.87	0.20	145.58	161	15.42
41.	*Semecarpus* sp.	Anacardiaceae	2.52	2.72	0.20	185.43	199.36	13.93
42.	*Shorea balangeran*	Dipterocarpaceae	1.90	2.38	0.48	270.33	317.83	47.50
43.	*Shorea leprosula*	Dipterocarpaceae	2.40	2.78	0.38	213.33	269.67	56.33
44.	*Shorea* sp.	Dipterocarpaceae	1.61	2.02	0.40	216.67	249.67	33.00
45.	*Swartzia pinnata*	Leguminosae	2.61	2.71	0.10	172	178	6.00
46.	*Syzygium* sp.	Myrtaceae	2.23	2.55	0.32	211	301	90.00
47.	*Tabernaemontana divaricata*	Apocynaceae	1.27	1.75	0.48	118	119	1.00
48.	*Tabernaemontana* sp.	Apocynaceae	1.27	1.75	0.48	118	147	29.00
49.	*Vernonia arborea*	Asteraceae	2.01	2.23	0.22	178	137.5	-40.50
50.	*Xylopia* sp.	Annonaceae	1.59	1.75	0.16	86	96	10.00

*Notes: D1=diameter at three years old (cm), D2=diameter after six months (cm), D3= diameter increase after six months (cm), H1=height at three years old (cm), H2=height after six months (cm), H3=height increase after six months (cm).

Symbol – (negative) indicates the plant's height decreased due to broken plant stems.