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EVALUATION OF REVEGETATION PRACTICES IN POST-MINED AREAS OF INDONESIA

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Running title: Revegetation practices in post-mined areas

ABSTRACT

With reference to the applicable regulations, mining companies in Indonesia are obliged to reclaim and return a post-mined area into its pre-mining condition. Revegetation, as part of reclamation activity, performs a significant role in rehabilitation of degraded post-mined areas to productive land uses. Therefore, this study aimed to assess the tree growth on the reclamation sites across four mining companies in East Kalimantan, South Sulawesi, South Sumatra, and West Java in Indonesia and if the companies hence met the legal requirements for site revegetation. The success parameters were based on applicable regulation of Ministry of Environment and Forestry (MOEF) P.60/Menhut-II/2009 and tree growth parameters (stem diameter, total height, and basal area). The parameters set by the regulation included revegetation realization, survival rate, tree density, tree health, species composition and rotation length. The four mining companies applied a two-phase planting method. *Enterolobium cyclocarpum* was mostly planted for the first phase; while for the second phase, slow growing and native species such as *Intsia palembanica*, *Syzygium polyanthum*, *Shorea* spp. and *Elmerrillia tsiampaca* were planted. The measurement results of tree growth parameters showed different performance over species and reclaimed sites. An extremely high growth was recorded in an E. *cyclocarpum* stand of the Mining Company in South Sulawesi reaching a stem basal area of 57.6 m^2ha^{-1} in only 11 years. All four mining companies strived to be in compliance with the regulation with scores of the revegetation success ranging from 15 to 25 out of 25 possible points. This favourable result may not be representative for all mining companies, as the ones assessed were voluntarily supporting this research. Additionally, each of the four companies made some distinct efforts in implementing post-mining revegetation, such as by establishing plot of *Melaleuca cajuputi* trees producing cajuput oil and polycultures of native species.

Keywords: Mining, reclamation, rehabilitation, reforestation, success parameters

INTRODUCTION

The increasing demands for raw materials in modern society have expanded extraction of mining commodities into ever more natural areas in remote regions. According to ICMM (2010), these regions are often those identified as priorities for biodiversity conservation and nature preservation. The mining sector in Indonesia plays a pivotal role for the country's economic development, which contributes approximately 9% to Indonesian Gross Domestic Product (PwC 2015). Mining commodities in Indonesia are classified into three categories: minerals, coal, and oil & gas. The mineral and coal reserves are distributed throughout the country spanning from Sumatra

to the Papua islands. In contrast to the contribution to economic development, the extraction and processing of mining reserves can cause environmental problems. These include extensive land disturbance, loss of forest cover and habitat, disruption of flora and fauna, changes in microclimate, surface and ground water contamination, emissions, dust and noise (McMahon *et al*. 2000; Greb *et al*. 2006). Considering these possible impacts, it is a legal obligation for the mining companies operating in Indonesia to ensure good mining practice and to conduct reclamation and revegetation on their post-mined sites. The aim of the reclamation of post-mined sites is to recover the degraded land and vegetation and return it to its original land use function.

Principally, the management of mining extraction is under the power of the state, which is the Government of Indonesia (GOI). The main regulatory authority responsible for the mining business is the Ministry of Energy and Mineral Resources (MOEMR). The Ministry of Environment and Forestry (MOEF) holds the responsibility for environmental and forestry issues when mining is conducted in the state forest areas covering 64% of the terrestrial surface of the country (Ditjen PKTL 2017). Mining activity is allowed in production and protection forest, but not in conservation forest. The MOEF is accountable for issuing the 'forest lending use permit' (*Izin Pinjam Pakai Kawasan Hutan*–IPPKH), a permit to utilize state forestland for development activities outside the forestry sector based on leasehold mechanisms.

Forestry science has taken a substantial role in determining how to reclaim post-mined areas in Indonesia, especially reforestation practices. This includes the selection of tree species, plant propagation, planting technique, plantation maintenance, and monitoring success indicators of the revegetation practices (Mansur 2013). Reclamation of post-mining concessions located in state forestland has to follow the regulations stipulated by the MOEF. Regardless of the land use, the reclamation activity is also assessed by the MOEMR for the release of reclamation bonds. These are allocated funds provided by mining concession holders as a guarantee to carry out post-mining reclamation. As a result, mining companies in Indonesia have to fulfil their responsibilities to be in compliance with the government regulations. The current study was aimed at evaluating how four mining companies in Indonesia, which voluntarily participated in the study, implement revegetation as a component of the reclamation program based on the legal requirements.

MATERIALS AND METHODS

Study Area

The study was carried out in four mining companies including a Coal Mining Company in South Sumatra, a Gold Mining Company in West Java, a Coal Mining Company in East Kalimantan, and a Nickel Mining Company in South Sulawesi, who supported the research. The selection is hence a positive selection in the sense that other companies that were approached did not respond to

the request to take part in the study. The location overview and companies' mining commodities are depicted in Figure 1. The concession areas are located in state forestlands, except the concession of the Gold Mining Company–West Java, which is located in non-state forestland.

Figure 1 Map of Mining Companies' Locations and Their Commodities

Sampling Procedure and Sample Size

Referring to the MOEF regulation for evaluation of reclamation in state forestlands (*Peraturan Menteri Kehutanan No. P.60/Menhut-II/2009*), this study used systematic sampling with a random start. The sampling intensity employed included 5% of the revegetated areas, and the size of the sampled plots was 40 m x 25 m (0.1 ha). Since the size of these areas varied in each company and the areas were scattered throughout the concession, this study stratified the compartments of the revegetation area based on the planting years. Accordingly, the sampling area and number of sampling plots were obtained by multiplying the sampling intensity (5%) and the size of the compartment in each planting year. The distance between each plot was around 50 to 100 m, which depended on the condition of the revegetation area. The sampling plots were then deployed based on the reviews of maps and an ArcGIS database, as well as a reconnaissance survey. The sampling plots established in this study had a total area of 7.8 ha and are presented in Table 1.

Table 1 Sampling Sites and Number of Sampling Plots in the Study Areas

Concession Name	Stand Age (years)	Total Revegetation Area (ha)[a]	Compart-ment Size (ha)	Sampling Plot (ha)	% Sampling Plot from Total Rev. Area

Coal Mining	1	26.2	5	0.3	1.1
S. Sumatra	2	17.1	2.2	0.2	1.2
	3	19.3	1.6	0.2	1.0
	6	48.9	7.1	0.4	0.8
	7	42.4	4.6	0.3	0.7
Gold Mining	1	1.5[b]	0.9	0.9	60
West Java	2	0.4[b]	0.2	0.2	62.2
	3	0.8[b]	0.2	0.2	25
	5	1.5[b]	0.3	0.3	20
	6	8.0[b]	0.2	0.2	2.5
Coal Mining	2A		2.7	0.2	
E. Kalimantan	2B	68.0	6	0.4	1.2
	2C		3.1	0.2	
	4A		4.1	0.3	
	4B	76.2	2.2	0.2	1.2
	4C		7.2	0.4	
	6	81.4	9.6	0.5	0.6
Nickel Mining	1	74.1	6	0.3	0.4
South	2	78.1	9	0.5	0.6
Sulawesi	4	90.0	7.6	0.4	0.4
	6A	114.9	2.6	0.2	0.3
	6B		3	0.2	
	11A	512.9	4	0.2	0.1
	11B		8.3	0.4	
	13	132.0	4	0.2	0.2
TOTAL SAMPLING PLOTS				7.8	

Notes: [a] The total revegetation area here is for both state forestland and non-state forestland

[b] Estimation of revegetation area planted with trees since some of the reclaimed sites were planted with herbaceous legume cover crops (LCC). A, B and C describe different stands of the same year.

Information and Data Collection

Research information and data were collected from primary and secondary sources. The sources of secondary data were mainly companies' data regarding their reclamation and revegetation programs. The primary data were collected through observation and forest inventory that involved measurement of parameters for evaluating revegetation success. The main reference used for assessment was the MOEF Regulation P.60/Menhut-II/2009 regarding Assessment Guideline of Forest Reclamation Success. The parameters observed and recorded, based on this regulation, were living trees (survival rate), tree density (number of trees/ha), tree health, and species composition based on rotation length groups (short rotation and long rotation species). The tree health status was visually observed based on vigour assessed by leaf colour, stem form, crown form, and symptoms of diseases. The growth parameters that were measured included stem diameter at breast height (DBH) and total tree height. The DBH was taken at 1.3 m from the ground using a diameter tape. Planted trees that were below this height were recorded and counted as living

trees. For the purpose of assessment using the GOI regulation, planted trees with bifurcation (two stems) or more were counted as a single tree. However, all the stems were individually measured for basal area determination. The total height of trees between 1 and 7 m was measured using a scaled stick, while for trees above 7 m, a Haga hypsometer was used for height measurement.

Data Analysis

The success parameters determined by GOI regulations included: (i) revegetation area planted (actual) compared to target area (plan) (%); (ii) survival rate (%); (iii) tree density (number of trees/ha); (iv) species composition (%); and (v) tree health (%).

i. The actual revegetation area was compared to the planned revegetation area (in hectares), based on a report review of the company's reclamation activity submitted and approved by the GOI.

ii. Survival rate was analyzed by comparing the number of living trees in a plot with the planned planted trees.

iii. Tree density was analyzed by dividing the total number of living trees in a plot by the plot area. This was then compared to the minimum required density of 625 trees/ha.

iv. For species composition, the number of trees considered as long rotation species was divided by the total number of living trees in the plot. The GOI regulation requires the post-mined areas to be revegetated using locally known species, either native or exotic, and which are categorized as long rotation species. The preferred planted trees are those generating high economic value products such as timber, resin, and fruits. Due to the absence of a national classification for rotation length categories, to analyze this parameter, a rotation length category for forest plantation developed by The Food and Agriculture Organization of the United Nations (FAO 2001) was used as a reference. For the assessment criteria of long rotation species, this study used the threshold of medium and long rotation length categories, which was $\geq$20 years.

v. Tree health was analyzed by comparing the healthy trees with the total number of living trees in a plot.

The next step was to score the parameters as determined by the regulation, the results of which are presented in Table 2. Based on an equal score weight of each of the five parameters and five scores per parameter, the maximum score was 25. The result is stated by comparing the total score obtained in each stand age with the maximum score. The analysis of growth parameters included the mean values of DBH, total height, and stem basal area. The stem basal area was determined using the formula $g = \pi/40000 \times d^2$, where g is the stem basal area in m^2, π is 3.1415,

and d is the average DBH in cm. The stand basal area G in m^2/ha was determined by dividing the total g mean values in m^2 of a plot by the plot size in hectares.

Table 2 Scoring of Revegetation Success[a]

Parameter	Assessment Standard	Score
Revegetation Area (actual planted area vs. targeted area)	1. ≥ 90%	5
	2. 80-89%	4
	3. 70-79%	3
	4. 60-69%	2
	5. < 60%	1
Survival Rate	1. ≥ 90%	5
	2. 80-89%	4
	3. 70-79%	3
	4. 60-69%	2
	5. < 60%	1
Tree Density	1. ≥ 625 trees/ha	5
	2. 551-625 trees/ha	4
	3. 474-550 trees/ha	3
	4. 400-475 trees/ha	2
	5. ≤ 400 trees/ha	1
Species Composition (long rotation species)	1. ≥ 40%	5
	2. 30-39%	4
	3. 20-29%	3
	4. 10-19%	2
	6. <10%	1
Tree Health	1. ≥90%	5
	2. 80-89%	4
	3. 70-79%	3
	4. 60-69%	2
	7. <60%	1

[a]The MOEF Regulation P.60/Menhut-II/2009

RESULTS AND DISCUSSION

Revegetation Establishment

Each mining company used a two-phase planting method. The first phase planting included the light demanding and pioneer species, which were mostly fast growing to provide shade to the species of the second planting phase. After 2-3 years, or when the crowns of pioneer species provided enough shading, the second planting was implemented. This second planting phase, called enrichment planting, included shade-tolerant slow growing species. The five most dominant tree species planted by each mining company are presented in Table 3.

Table 3 Five Most Dominant Trees Planted in the Reclaimed Sites of Each Mining Company

Company	Tree Species
Coal Mining Company	*Enterolobium cyclocarpum*[a]*, Swietenia macrophylla, Intsia*

South Sumatra	*palembanica, Melaleuca cajuputi*[a]*, Tectona grandis*
Gold Mining Company West Java	*Enterolobium cyclocarpum*[a]*, Gliricidia sepium*[a]*, Melaleuca leucadendron*[a]*, Syzygium polyanthum, Aporosa aurita*
Coal Mining Company East Kalimantan	*Cassia siamea*[a]*, Shorea leprosula, Samanea saman*[a]*, Shorea balengeran, Melaleuca cajuputi*
Nickel Mining Company South Sulawesi	*Cassia siamea*[a]*, Vitex cofassus, Enterolobium cyclocarpum*[a]*, Casuarina junghuhniana, Elmerrillia tsiampacca*

Note: [a] First planting species

Assessment of Plant Growth Parameters

As a result of different planted species, the plant growth in all assessed revegetation sites differed in each company, as depicted in Figure 2. In general, the mean values of tree height (H) and diameter (D) in the assessed reclaimed sites increased with age. According to Lamb (2011), besides the selected species that are planted, the most important factors that determine plant growth in post-mined site conditions are soil properties and topography. Mansur (2013) propounded that the type of extracted minerals affects soil fertility in the mined area. As this study did not investigate soil properties, the potential influence of soils on plant establishment and growth cannot be estimated.

The total stem basal area is positively correlated to the crown projection area (Supriyanto *et al*. 2001). Hence, the basal area (BA) values with stem numbers are good revegetation success indicators. The highest BA value was observed in the 11-year-old stand (11A) of the Nickel Mining Company–South Sulawesi (57.6 m^2ha^{-1}). The prominent species that established the highest BA value in this stand was *E. cyclocarpum*. However, this particular BA value seems exceptionally high, maybe caused by border tree effects in the small 2000 m^2 plot, and the largest stem number. In each mining site, the values of BA varied in each of the assessed stand ages. For instance, in the reclaimed site of the Coal Mining Company–South Sumatra, the BA value of the 6-year-old stand was higher than that of the 7-year-old stand. This was because the 6-year-old stand had fast growing *Paraserianthes falcataria* trees and the 7-year-old stand did not. A similar case was also observed in the Gold Mining Company–West Java, with the species *E. cyclocarpum*. In this case the 3-year-old stand had a higher BA value than the 5-year-old stand. Based on field observations and an interview, the possible cause for growth stagnancy in the 5-year-old stand B was high soil acidity (Dody Rahadi, Pers. Comm., 5th May 2016). In the Coal Mining Company–East Kalimantan, the 2- and 4-year-old stands sampled in different locations had different BA values, even though the species planted were the same *Cassia siamea*. Based on observation, this was related to a lack of plant maintenance, such as weeding, at stands 2B and 4B, which led to relatively poor growth. Different BA values were also observed in the 6- and 11-year-old stands of the Nickel Mining

Company–South Sulawesi. In this case, the result was due to a different number of stems and different stem diameters of each species.

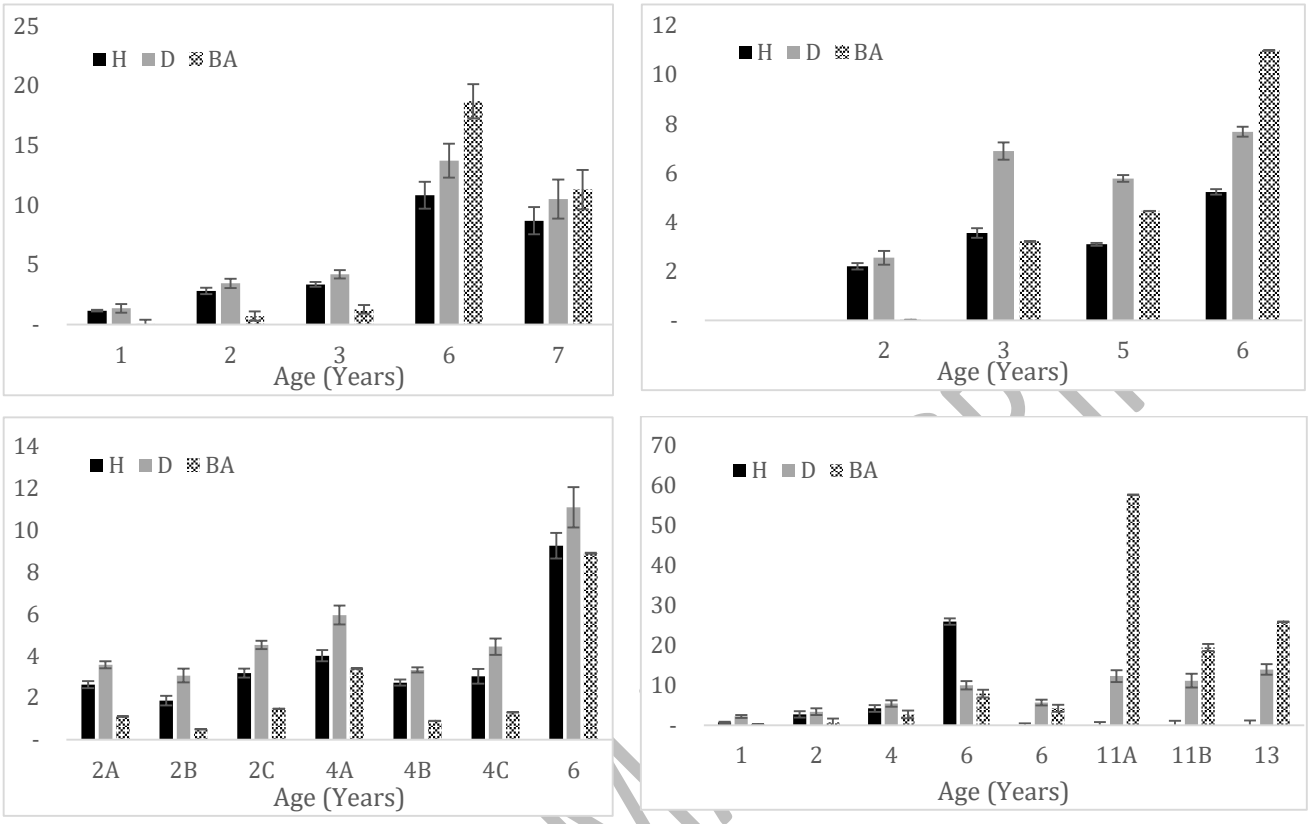

Figure 2 Mean Tree Height (H), Mean Stem Diameter DBH (D), and Stem Basal Area (BA) for Different Stand Ages in the Reclaimed Sites. The differentiation labelled A or B in a single year refers to different stands of the same year.

Revegetation Performance Based on GOI Regulation

In relation to performance and compliance with the GOI regulation, the assessment of revegetation showed that values of the assessed sites ranged from 74% to ≥ 100%. The reason for variation in revegetation realization is usually because some of the mining sites that have to be reclaimed by the planned year are still being used for mineral extraction and material dumping. Therefore, the actual revegetation area at these sites was lower than planned. Conversely, on some sites, mining activities closed earlier and could be reclaimed sooner. Hence, the actual revegetation performance was higher than planned. The mining company is obliged to report to the government any deviation between the planned and the actual revegetation for further evaluation.

Regarding the survival rate parameter, the evaluation ranged from 46% to ≥100% in all assessed reclaimed sites for different stand ages. The two lowest survival rates were found in Gold Mining Company–West Java and Coal Mining Company–South Sumatra with values of 46% and 58%, respectively. The reason for this observation in the 3-year-old stand of the Gold Mining Company was that the high mortality was related to insufficient plant maintenance, especially poor

weeding. The area was overrun by imperata grass. In the case of the Coal Mining Company–South Sumatra, the problem encountered in the 6- and 7-year-old stands was spontaneous coal combustion. Spontaneous fires in coal mining sites have become an area of concern worldwide (Singh 2013). As a result of the low survival rates, the company has to replant both stands. The Nickel Mining Company–South Sulawesi, however made considerable efforts on revegetation maintenance. They carried out careful monitoring of the plants within the first two years of establishment. Any dead plants were immediately replanted. Further, weeding was continued up to year four for both first- and second-phase plantings. The two coal mining companies only weeded up to year three. The Gold Mining Company–West Java conducted weeding as required.

The tree density in the assessed reclaimed sites ranged from 433 trees/ha to 1,635 trees/ha. A detailed comparison of tree density in each mining company is presented in Table 3. The Nickel Mining Company–South Sulawesi led performance on this parameter, and the highest plant density was observed at stand 11A (1,635 trees/ha). The lowest stand densities were observed in the 7- and 6-year-old stands of Coal Mining Company–South Sumatra caused by spontaneous coal combustion (Sukono, Pers. Comm., 20th April 2016). The other low-density case was found in stand 4C in the reclaimed site of Coal Mining Company–East Kalimantan, with only 450 trees/ha. This was because the reclaimed site was on a slope. This indicates that careful planning and maintenance are required for revegetation located on slopes. Recommended measures for sloped areas include: (1) planting of legume cover crops and ensuring soil coverage to prevent erosion; and (2) establishing high stocking of pioneer and fast-growing trees in the early planting. Based on the cases of the Coal Mining Company–South Sumatra, it is essential to increase plant stocking in the early establishment phase to achieve the minimum tree density.

Regarding tree health, there were no serious problems identified in all assessed stand ages in terms of plant diseases and pest infestation. The common problems found were mostly yellowing leaves and leafless trees. A crucial health problem was found in the 5-year-old stand at the Gold Mining Company–West Java caused by acidic soil. The planted species of *E. cyclocarpum* and *S. saman* were mostly stunted, yellowish, and without foliage in the rainy season.

Table 4 Comparison of Tree Density for the Different Mining Companies

Stand Age (Years)	Density (trees/ha)			
	Coal Mining Company–S. Sumatra	Gold Mining Company–W. Java	Coal Mining Company–E. Kalimantan	Nickel Mining Company–S. Sulawesi
1	523	1,072		503
2	543	1,074	(A) 610 (B) 585 (C) 700	468

3	1,120	515		
4			(A) 893 (B) 450 (C) 803	1,328
5		960		
6	445	1,080	828	(A) 1,575 (B) 1,100
7	433			
11				(A) 1,635 (B) 985
13				1,060
*Planned tree density (N/ha)**	***750***	***1,111***	***937***	***1,400***

Note: *For the year of reclamation according to GOI stipulation

In this case, it is worthwhile replanting the reclaimed site with *M. cajuputi* that can tolerate acidic soil (Doran and Turnbull 1997). Further, water logging was encountered in some reclaimed sites of the Coal Mining Company–South Sumatra. In order to prevent impediment to the revegetation plants, carefully planned and implemented land preparation is required. The company also took action by planting species tolerant to waterlogging, such as *Nauclea orientalis* and *M. cajuputi*. According to Orwa *et al*. (2009), these two species were observed to be associated with swampy areas. Additionally, *M. cajuputi* is fire resistant (Chokkalingam *et al*. 2007) and able to tolerate infertile soil, and the roots have aerial and adventitious growth habits in waterlogged and flooded areas (Doran and Turnbull, 1997). The Nickel Mining Company–South Sulawesi also experienced some plant diseases in 2008 caused by fungal infestation of *P. falcataria*. Currently, the reclaimed sites are mostly planted with *E. cyclocarpum*. Based on field observation in this company, there was no indication of diseases on *E. cyclocarpum*.

The last parameter assessed is species composition of long rotation length, with a minimum of 40% of the total living trees required. The percentage found in each company ranged from 0 to 93%. The 13-year-old stand in the Nickel Mining Company–South Sulawesi reached 93%, comprised of 12 native long-rotation species. The strong point of the revegetation practice in this company was the employment of polyculture methods. The company had planted slow growing and long rotation length species since the first phase of revegetation practice. In each assessed stand of this company, the species diversity consisted of 12 to 29 species of both short and long rotation categories. Considering the status of the mining concession of non-state forestland, the Gold Mining Company–West Java does not have any obligation to plant diverse species as required by the MOEF regulation. However, the company strived to plant native species. The planting comprised six to 36 species of both short and long rotation species. In the reclaimed sites of the Coal Mining

Company–South Sumatra, the number of species planted in each stand consisted of two to eight species, mixed between short and long rotation species. Based on field observation, the company has developed a pilot project to produce cajuput oil extracted from *M. cajuputi ssp. cajuputi* to enhance sustainable land use once the concession has ceased. However, in order to increase species diversity, other possible species to be planted as a trial should include *Fagraea fragrans* (Mindawati *et al*. 2014) and *Alstonia scholaris* (Martawijaya *et al*. 2004 p. 123). These two species can tolerate waterlogging and poor soil condition. In the Coal Mining Company–East Kalimantan the species composition value was the lowest. The reason for the absence of long rotation species, especially in the 2- and 4-year-old stands, was because in these stands, enrichment planting had not yet been performed. For the stand 4A, the company could carry out enrichment planting soon since the crown shelter of the first planting has already become established. Additionally, to diversify the planted species, the company could use native and long rotation species such as *Peronema canescens* and *Vitex pubescens*, which have also been planted in some reclaimed sites of this company. Species diversity for rehabilitating post-mined areas, according to Lamb (2011), is necessary to anticipate some losses in the lifetime of the revegetation stands. Further, the inclusion of endangered species in the reclaimed sites is vital for biodiversity conservation. The four assessed mining companies have planted endemic species, as well as some endangered species of their regions.

In light of the above, each company has demonstrated its commitment to be in compliance with the applicable regulation. Detailed total scores for revegetation evaluation based on the MOEF Regulation P.60/Menhut-II/2009 in each company are summarized in Table 5. Referring to Table 5, the 1- and 6-year-old stands of Gold Mining–West Java and stand 11A of the Nickel Mining Company–South Sulawesi reached a maximum score of 25. The current scoring results cannot be classified as good, medium, or poor in terms of the level of compliance since the scores have to be integrated with other parameters regarding land preparation and erosion control as required by the regulation. For the assessed reclaimed sites with age greater than three years, and that have lower scores (<20), each company is able to improve the performance through intervention efforts such as maintenance.

Table 5 Comparative Results of Average Total Scores for Revegetation Evaluation of the Mining Companies

Stand Ages (Years)	Total Scores of Revegetation Evaluation			
	Coal Mining Company–S. Sumatra	Gold Mining Company–W. Java	Coal Mining Company–E. Kalimantan	Nickel Mining Company–S. Sulawesi
1	19	25		23
2	19	23	19	19

			20	
			20	
3	24	18		
4			20	24
			15	
			22	
5		18		
6	18	25	23	23
				20
7	16			
11				25
				23
13				23
Average	**19**	**22**	**20**	**23**

In the light of the above, an additional success criterion would be useful to be included in the revegetation assessment. The GOI could add to its evaluation a standard revegetation growth table with ranges of tree density and ranges of basal area related to the age of the reforestation. With these criteria, both company and GOI could evaluate the growth performance of whether it is continuing or stagnating at a certain age. Therefore, any immediate measures could be taken for preventing adverse revegetation results. Furthermore, the assessment result will demonstrate both quantity and quality of the reclaimed sites. Additionally, based on current revegetation implementation, common silvicultural practices, such as pruning and thinning, are hardly implemented. However, this approach should then be in accordance with applicable regulations, land use status, and the objective of post-mined area designation.

CONCLUSION

Based on field observation in four mining companies, and with reference to MOEF Regulation P.60/Menhut-II/2009, each mining company has aimed to be in compliance with the regulation on revegetation with scores ranging from 15 to 25 out of 25 possible points. This favourable result may not be representative for all mining companies, as the four companies included were ones that positively supported this research. With regard to the plant growth parameters, the result varied in each company based on the type of species planted. To improve the assessment of revegetation success criteria, it would be beneficial for the GOI to take into account growth parameter of basal area on the evaluation. This criterion together with tree density could be integrated into a standard growth table related to age of revegetation stand. It is expected that the growth performance could be monitored so that the assessment result will demonstrate both quantity and quality of the reclaimed sites.

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