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The process of rehabilitation of mined forest lands toward degraded forest ecosystem recovery in Kalimantan, Indonesia

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Abstract. *Sudarmadji T, Hartati W. 2016. The process of rehabilitation of mined forest lands toward degraded forest ecosystem recovery in Kalimantan, Indonesia. Biodiversitas 17: 185-191.* An overview of mined forest lands at East and Central Kalimantan Indonesia was conducted to determine most important influencing factors supporting degraded forest ecosystem recovery. Consecutive stages of rehabilitation processes consist of reclamation-*backfilling*, *re-contouring*, *re-shaping*, *topsoils spreading*, and revegetation-*land preparation*, *planting*, *maintenance* covering minimum topsoils spreading, soil acidity, plant hole size, soil improvement application (*dolomite*, *organic-inorganic fertilizers*), vegetation planting (*plant species selection-quality and site matching-verified plant material sources*, *hardening-off*, *planting techniques*), and land management implementation. The potential degraded forest ecosystem recovery was shown by cover crops and fast growing species plant and undergrowths, survive primary species, decreasing surface run-off/overland flows following increasing soil infiltration capacities, decreasing soil erosion rate and it's erosion hazard, and an improved environments as habitat for invading wildlifes. The general characteristics of potential degraded forest ecosystem recovery after rehabilitation processes are: spread soil materials thickness > 70 cm, bulk density $\pm$ 1,2 g.ml^{-1}, soil acidity > 5,5, macro nutrients (N, P, K, Ca, Mg)-low to moderate, decreasing overland water flow following increasing soil infiltration capacity-moderate to high, decreasing soil erosion rate-very low to moderate, decreasing erosion hazard level-very slight to moderate, growing plants of fast growing species with significant layers and land cover, and growing interline planted primary species. Viewed from the ecological aspect, in the revegetated degraded forest lands wildlife such as insects, birds, reptiles, amphibians and small mammals were found feeding and also permanently living in ecosystem regeneration following gradual habitat improvement. The ecosystem status was identified as a progression towards degraded forest ecosystem recovery.

Keywords: Degraded forest, ecosystem, rehabilitation process, reclamation, revegetation

INTRODUCTION

Various natural resources utilization and environmental management must be able to minimize the negative impacts and retain the quality and it's sustainability for people welfare. For this reason, coal mining companies have an obligation to observe-monitor and manage potential emerging environmental impacts along with their mining operation. It has been widely known that coal mining operation causes a significant impact to the environment (Ibarra and Heras 2005). Degraded land is an area that either by natural causes or more by directs or indirect causes of human action, has been altered or modified from its natural state (Santamartaa et al. 2014).

It is therefore, environmental management must follow it's consecutive mining operation stages starting from clearing of the vegetation-topsoils striping and stockpiling-mining waste treatment, the coal mining process-land reclamation and revegetation of the disturbed site. It is also very clear that these activities determine efficient and rational coal utilization as non-renewable natural resources. However, coal mining operations as far as possible, must enhance a better life for mankind and achieve a brighter future. Environmental disturbances, especially forest lands degradation, must be seriously considered for the next generation who will utilize this land.

Coal mining operations contribute significant impacts both on and off-sites to the environment (Bradshaw 2002) resulting in heavy degraded lands and massively altered forest ecosystem. General features of mined lands are the dumping of overburden with disturbed soil, fragmented rocks mixed with coal fines without organic materials, bad water drainage, low soil water, compacted soils and with high soil temperatures (Datar and Mulligan 2011; Zhenqi et al. 2012). Such disturbed soil and overburden sites are unable to perform the main soils function to provide a plant growth media and conservation of water. Moreover, degraded lands are also characterized with bad drainage and low water holding capacities and highly compacted soils. To achieve good mining practices along with the many rules for coal mining operation, land rehabilitation practices must be carried out in order to achieve recovery of a mined forest lands (Siswanto et al. 2012). These rehabilitated lands would also be expected to be a productive land (Devathaa et al. 2015).

The open pit/cast method of coal mining operation which is commonly applied at Kalimantan Indonesia cause great and massive changing to the landform and therefore they need rehabilitation to recover and retain the environmental function capacity for supporting various rehabilitated ecosystems (Kilowasid et al. 2011). Specifically, mined lands suffer a drastic soil fertility deficit and a poor microclimate, with a huge increase of water flow and runoff causing a significant increase in soil erosion and sedimentation away from the disturbed site.

The rehabilitation processes require a specific knowledge and experiences with respect to soil formation and development, proper and practical techniques of mined land rehabilitation, plant species selection with appropriate site matching, and also planting techniques and vegetation maintenance after the rehabilitation process. Degraded forest lands rehabilitation has been carried out as an initial effort to restore altered ecosystem through reclamation activities of *backfilling*, *re-contouring*, *land leveling*, *re-shaping* and *topsoils spreading*, followed by revegetation process as such as *land preparation*, *planting*, and *maintenance* of the rehabilitated lands.

The main objective of this study was to identify the characteristics of mined forest lands for potential recovery after rehabilitation processes. The expected result of the study was to develop and/or improve the design of land rehabilitation processes enhancing degraded forest ecosystem recovery.

MATERIALS AND METHODS

Observation and fieldwork focused on several soil characteristics, water flows and infiltration, soil erosion and sedimentation, revegetation plants, wildlife (fauna), and ecosystem status were conducted. The study sites were six rehabilitated forest lands in Kalimantan, Indonesia, namely PT Berau Coal (BC), PT Kaltim Prima Coal (KPC), PT Trubaindo Coal Mining (TCM), PT Kitadin (KTD), and PT Kideco Jaya Agung (KJA), all situated in East Kalimantan, as well as PT Multi Tambangjaya Utama (MTU) in Central Kalimantan, covering reclamation processes (*backfilling*, *re-contouring*, *re-shaping*, *topsoils spreading*) and revegetation processes (*land preparation*, *planting*, *maintenance*), taking into account the consecutive stages of mined land rehabilitation.

Some minipits were selected as representatives of mined forest lands of different ages of vegetation to asses and diagnose the physical and chemical soil characteristics for indicating soil recovery and development with respect to the assessment of water flow and infiltration capacity.

Rainfall data and field observation of topographical condition, vegetation growth, land coverage density, soil and water conservation practices were used to estimate the potential soil erosion using Universal Soil Loss Equation (USLE) approach. Secondary data of biodiversity and habitat improvement studies at the same sites was used to construct scenario of degraded forest ecosystem recovery.

RESULTS AND DISCUSSION

Rehabilitation of ecosystem functioning

Forest succession is an ecosystem process in which the ecosystem change in the form of flora or fauna diversity is measured. Progressive succession is the normal sequential development of communities, from simple communities with few species and low productivity to the optimum sustainable in a given habitat or environment. Conversely, retrogression is a successional change usually from an existing climax community leading to a less diverse and less structurally complex community. It is usually triggered by an environmental factor. Primary succession is a succession in an area without any previous vegetation. Secondary succession is a succession that occurs in a degraded area with some remaining vegetation or an area where the vegetation has been disturbed. Progressive succession shows species increase whereas species decrease defines retrogressive succession. In the forested or vegetated areas seriously disturbed there might be complete failure in succession which means that the earlier condition or historical state could not be recovered.

One would expect the revegetation of mined-out lands to accelerate ecological processes to achieve the condition as of a pre-mining operation or even better. The main consideration in plant species selection is based on not only having high tolerance to the extremely degraded soil condition but also to the capacity of the plants to recover degraded ecosystem functioning (Zhenqi et al. 2012). However, there is a possibility that the tree plant species selected could not fulfill such expectations. Some species are tolerance of the extreme condition but less favorable for enhancing ecosystem recovery due to their intolerance to invading species and thus triggering a retrogressive succession. For these reason, it is important to understand that the potential of the natural vegetation to alternating the impact of the coal mining operation and at the same time also increase vegetation structure and composition following the rehabilitation process (Isahak et al. 2013; Humsa and Srivastava 2015).

Lands rehabilitation process

The main environmental principles for reducing land degradation are to maximize vegetation cover to prevent erosion, replace nutrients removed, and to put in place structures so as to reduce the speed and volumes of water flow over the soil (Morgan 1996; Blinkov et al. 2013; Gashaw et al. 2014; Dyguś 2015,).

The process of rehabilitation is studied in a consecutive activity of reclamation and revegetation in order to accelerate the recovery of degraded forest lands. Soils provide a plants growth medium with satisfactory aeration and drainage to ensure the development of a root system to absorb macro and micro nutrient. In this rehabilitation study, reclamation process assures sufficient thickness of soil through topsoils spreading and re-contouring, in order to control excessive water drainages. In order to achieve the improvement of soil aeration organic materials were added followed by immediate planting of land cover crops. Figure 1 shows the result of topsoils spreading at TCM, MTU and BC, while Figure 2 illustrates the initial planting at the same sites.

Based on the results of observation, field works and laboratory analysis; the recovery processes of mined forest lands are highly dependent on the determining factors and steps of rehabilitation which consist of reclamation and revegetation processes. Technically, the minimum standard required for mined lands rehabilitation are spreading of topsoils of a minimum of > 70 cm thickness, soil pH of > 5,5, planting holes with 40 x 40 x 40 cm in size, soil amelioration with dolomite, organic and/or chemical fertilizer application, vegetation planting and followed by intensive rehabilitated lands management. The summary of the general characteristics of mined forest lands potential recovery after rehabilitation works is shown in Table 1.

The ecosystem function of mined forest lands after rehabilitation processes shows a positive trend to be recovery as visually shown in Figure 3 to Figure 8.

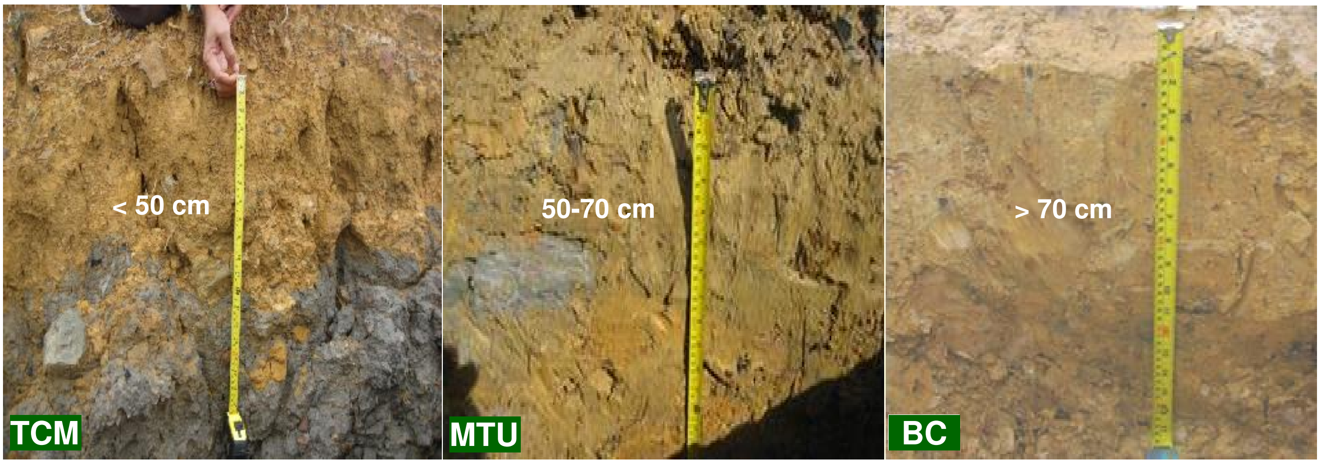

Figure1. Land Preparation) at Mined-out Lands of TCM (<50 cm), MTU (50-70 cm), and BC (>70cm)

Figure2. Planting after reclamation works at TCM (*fast growing species*), BC (*land cover crops*), and MTU (*land preparation-planting holes*)

Table 1. General characteristics of mined forest lands potential recovery after rehabilitation processes

Component	Parameter	Description
Soil physics	Soil materials thickness	$\geq$ 70 cm
	Bulk density	$\pm$ 1,25 $g.ml^{-1}$
Soil chemistry	Soil acidity (pH)	> 5,5
	Macro nutrients	Macro nutrients (N, P, K, Ca, Mg : Low to Moderate
Hydrology	Overland water flow	Decreasing in line with the increase of soil infiltration capacity: no significant detention of water
Erosion	Rate	Decreasing soil erosion rate: Class-Very low to Moderate, Hazard-Very slight to Moderate
Revegetation	Plants	Fast growing species form land coverage both of trees and herbs or grasses, interline planted primary species grow well
Wildlife	Fauna	Invading insects, birds, amphibians, reptiles, small mammals
Habitat	Improvement	Improved habitat: microclimate-air and soil temperature, relative humidity, solar radiation intensity, foods and coverage.
Ecosystem	Status	Prospective with coefficient of similarity 60-70%, completely developed food web, invading herbivores, carnivores, predators, but no top predator as yet.

Figure 3. Rehabilitated lands management at TCM (*fast growing species-4 years*)

Figure 4. Rehabilitated lands management at BC (*fast growing and primary species 10-12 years*)

Figure 5. Rehabilitated lands management at MTU (*fast growing species 4-5 years*)

Figure 6. Rehabilitated lands management at KTD (*fast growing and agriculture commodities 1-2 years*)

Figure 7. Rehabilitated lands Management at KPC (*fast growing, primary species > 10 years, palm oil, soil and water conservation structure*)

Figure 8. Rehabilitated lands management at KJA (*fast growing and primary species > 12 years*)

Mined forest lands recovery potential

After mining activities are complete, the topography and physical soil properties are reconstructed in an attempt to establish the foundation of a self-sustaining ecosystem (Arnold and Williams 2016). However, soil properties are still markedly different compared to unmined areas, including higher bulk density. Degraded lands initially showed soils disturbance especially that of soil structure and pores destruction. It was found important differences in hydrological functioning and erosion response of soils under different land uses and vegetation types (Ferreiraa et al. 2015). For this reason, degraded lands have to be assessed as recovery processes based on a soil characteristics approach (Agassi 1996). Analysis of erosion potential dynamics as a simple indicator of mined lands revegetation showed that to reach the status of low (L) and very low (VL) erosion rate require about 5 (five) years (Table 2).

Vegetation is the first biological component which is very important as primary producer providing nutrients, ground covers, clean air and habitats for various other life forms. The vegetation life form is a real measure of the soil quality (An et al. 2013), and also the wildlife. Therefore, soils, vegetation and wildlife are unseparable and strongly inter-dependent three components of rehabilitated habitat.

The seasonal emerging plants creeper species have an important role as an undergrowth land cover improve the microclimate, and also supply organic matter and enhance the return of mesofauna (invertebrates). Mesofauna return is closely related to vertebrate (reptiles and amphibians) recover, many as predator on the mesofauna. Therefore, revegetation with plants, whether planted or naturally emerging are very important in the mined forest lands recovery process.

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The individual presence and frequency of birds are an interesting and useful monitoring. Some changing trends in composition and population richness of bird species can be used as a bio-indicator of environmental changing. Similar with birds as bio-indicator of environment change, other animals such as butterflies, dragonflies, bumble bees, reptiles and amphibians can also be used as bio-indicators.

Soil erosion potential is influenced by several factors including vegetation development (Dantas et al. 2015). In order to decrease the risk of soil of erosion rehabilitated forest lands have to be intensively managed for least the first 5 (five) years especially in relation to land preparation and the intensity of vegetation maintenance. Land rehabilitation process must initially be introduced to control surface water flow (Lei et al. 2015). The plants grow and provide coverage to protect soil surfaces form excessive erosion.

Ecological potential recovery of mined forest lands

The intentional alteration of a site to establish a defined indigenous is a historic ecosystem. The goal of this process is to emulate the structure, functioning, diversity, and dynamics of the specified ecosystem (Aronson et al. 1993). With respect to the afore-mentioned, revegetated land recovery is made possible by reclamation process namely land preparation to make the land functional as a medium for plant biomass production. Post mining revegetated land management result in vegetation development of both vertical and horizontal cover.

In the early stages, stabilization of mined lands by growing a cover crop reduces soil erosion and gradually forms a better microclimate by decreasing air and soil temperatures and increasing air and soil humidities. The growth and development of vegetation supplies organic materials into the soils thus increasing soil fertility. In times, advance growth and development of vegetation contributes to the reduction of soil erosion potential and also forms a more favorable microclimate. These conditions attract various animals (wildlife) to feed on rehabilitated mined lands, and more over living and enhancing the regeneration of the ecosystems (Figure 9).

The invading wildlifes can be potentially used as bioindicators for assessing the progress of ecological recovery of degraded lands (Laurila et al. 2015). Also, interline planting by using primary species-dipterocarps species is a long-term investment to achieve more rapid recovery of mined lands. Cover crops and fast growing species planted in the early stages and rapidly reaching flowering and fruiting make an important contribution to bridging the growth developing of primary species to the ultimate goal of degraded forest lands rehabilitation. A higher diversity of invading wildlifes to feed, live and regenerate animals populations shows a clear direction and the steps of mined forest lands recovery that is required.

Table 2. Potential soil erosion dynamics following land coverage development at three sites

Sites[1]	Classification of soil erosion rate (classes of ton/ha/yr)[2]							
	Open	<2Yr	2-4Yr	4-6Yr	6-8Yr	8-10Yr	>10Yr	Original
SMO	(VH)	(H)	(L)	(L)	(VL)	(VL)	(VL)	(VL)
BMO	(VH)	(M)	(L)	(L)	(VL)	(VL)	(VL)	(VL)
LMO	(VH)	(H)	(H)	(VL)	(VL)	(VL)	(VL)	(VL)

[1]SMO, BMO, LMO: Sambarata, Binungan, Lati, [2]VR = Very Low (<15 $ton.ha^{-1}.yr^{-1}$), L = Low (15-60 $ton.ha^{-1}.yr^{-1}$), M = Moderate (60-180 $ton.ha^{-1}.yr^{-1}$), H = High (180-480 $ton.ha^{-1}.yr^{-1}$), VH = Very High (>480 $ton.ha^{-1}.yr^{-1}$)

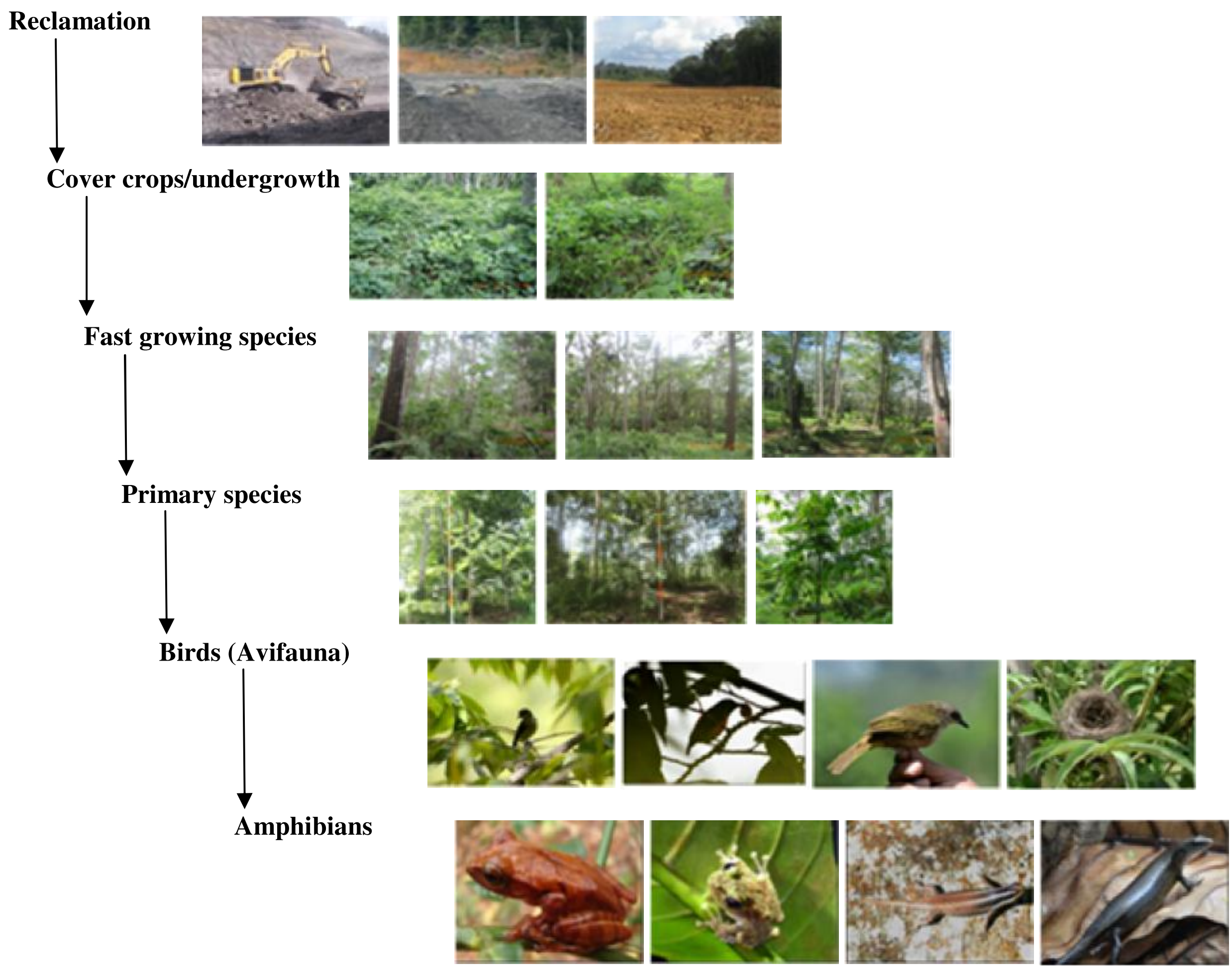

Figure 9. Steps in the rehabilitation processes and the recovery proccesses showing land coverage by vegetation and the invading wildlifes-birds (avifauna) and amphibians (herpetofauna)

To conclude, the most important factors and stages for land recovery are topsoils spreading (thickness and density), land preparation (planting hole, soil amendment/ amelioration materials), planting (plant materials, techniques), and rehabilitated forest lands management (replanting dead trees, maintenance, fertilization). The potential recovery of mined forest lands can be shown by revegetation plants (land cover crop and fast growing species grow combined with undergrowth and interlayered crown, primary species are interline planted, decreasing soil erosion rate (erosion hazard class: very low to moderate, erosion hazard level: very slight to moderate, decreasing overland flow increasing soil infiltration capacities), and invading animals (wildlife) feeding, multiplying and ecosystem regeneration. Mined forest land potential recovery could be assessed through soil characteristics, overland flows, infiltration capacity, soil erosion and sedimentation, revegetation plants, invading wildlife and ecosystem status. Degraded lands are continuously recovering, the mined lands being on the right track to be recovery in time, as indicated by interaction between ecosystem components of forest ecosystems, hydro-orological conditions, improved microclimate, and also invading wildlife for regeneration of the ecosystem. The applications of rehabilitation (*reclamation* and *revegetation*) processes have significantly enhanced the recovery of mined forest lands and were the most important basis for the improvement of degraded forest ecosystems.

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