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SOIL AND VEGETATION ANALYSIS OF REHABILITATED AND UNREHABILITATED AREA IN AN INACTIVE COPPER MINED OUT SITE IN MOGPOG, MARINDUQUE, PHILIPPINES

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ABSTRACT

After 10 years of establishing rehabilitation strategies, the present study analyzed the soil (i.e. pH, organic matter, N, P, K, Cu, bulk density and water holding capacity) and plant diversity to evaluate the 10 year rehabilitation efforts carried out in an inactive copper mined out site of Consolidated Mines Incorporated (CMI) in Mogpog, Marinduque, Philippines by the then University of the Philippines Los Baños Bioremediation Team. During the revisit of the area in 2016-2017, the experimental site was divided into rehabilitated and unrehabilitated areas by establishing six (6) 20m x 20m quadrats. Comparison of soil samples was done through Student's *t test*, while vegetation analysis was done by measuring the plant diversity using the species richness and Species Importance Value (SIV). After 10 years of rehabilitation, there was a minimal difference in soil characteristics between rehabilitated and unrehabilitated area except for pH. Vegetation analysis showed significantly higher mean species richness under rehabilitated area as compared with the unrehabilitated area. The rehabilitated area was dominated by vines and trees and had greater number of seedlings and saplings, while grasses dominated the unrehabilitated area. These findings showed the benefits of rehabilitation established

Key words: bioremediation, mycorrhizal fungi, diversity, assessment

INTRODUCTION

Mining is a process of extracting valuable minerals or ores from the ground and is often considered to have destructive processes that damage the landscape and environment. Its impact ranges from loss of biodiversity, contamination of air, soil and water; erosion, and health-related issues due to harmful chemicals used in mining operations. Because of these, rehabilitation is imperative to restore mined out area to a state similar to its pre-mining condition as closely as possible (IRR of RA 9742). This aims to convert a mined-out area to an area with a safe and stable condition that minimizes potential risks.

In 2017, the Philippine government ordered the mining firms to allocate and deposit their budget for activities intended to protect the environment and develop the neighboring community, or their operation will be suspended. The Philippines also became the first among the 50 countries implementing the Extractive Industries Transparency Initiative, a global standard for open and accountable management of oil, gas and mineral resources, to achieve satisfactory progress (EITI, 2017).

A number of mining firms had rehabilitated their decommissioned sites and their periphery. The Solid Earth Development Corporation had recently opened its rehabilitated site for ecotourism, and Coral Bay has achieved 30% rehabilitation in comparison to its original state. However, Mines and Geoscience Bureau listed 31 mining sites in the country abandoned, inactive or closed. One of these is previously mined for copper by Consolidated Mining Inc. (CMI) in Mogpog, Marinduque which was left inactive for more than 28 years.

In 2006, the UPLB Bioremediation Team, a group of researchers from the University of the Philippines Los Baños (UPLB), identified the upper most part of the mined-out rock dumpsite in Barrio Capayang for their rehabilitation project. This was a major component under the *Jatropha* Program of UPLB. The study applied several interventions such as soil amelioration with the use of mycorrhizal fungi (5g per plant), lime (214g plant^{-1}) and compost (500g plant^{-1}) added and mixed in a one foot^3 hole, during field planting. In addition, NPK (14-14-14) fertilizer was applied to all plants at the rate of 25 g plant-^{1} (Aggangan et al. 2017).

The compost which was obtained from Folia Tropica Quick-Acting Organic Plant Food (Los Baños, Laguna) has the following analysis: 1.28% Total N, 1.05% Total P, 2.41% Total P_2O_3 (available P), 1.53% Total K, 1.84% Total K (water soluble K), 55.3% organic matter, 22 C:N ratio, and pH of 6.3. The Bioremediation Project focused on growth performance of rehabilitation species and microorganisms, including their ability to concentrate heavy metals (Aggangan et al. 2012; Cadiz et al. 2012; Llamado et al. 2013). Due to time constraint, the project team was unable to assess the long-term effects of rehabilitation in the mined out site, thus this study.

MATERIALS AND METHODS

The research area is a rock dumpsite of a copper mining operation by CMI within the boundary of Barangay Ino and Barangay Capayang in Mogpog, Marinduque, Philippines (Fig. 1). It is hilly approximately at 60 masl and located near a local mangrove forest and coastal zone (Cadiz et al. 2012). Beside the study area is a 450 m wide open- pit that is filled with waters which become sources of water for irrigation of nearby rice fields (Tulod et al. 2012). A total of six (6) quadrats were established on the topmost part of the inactive mined out site.

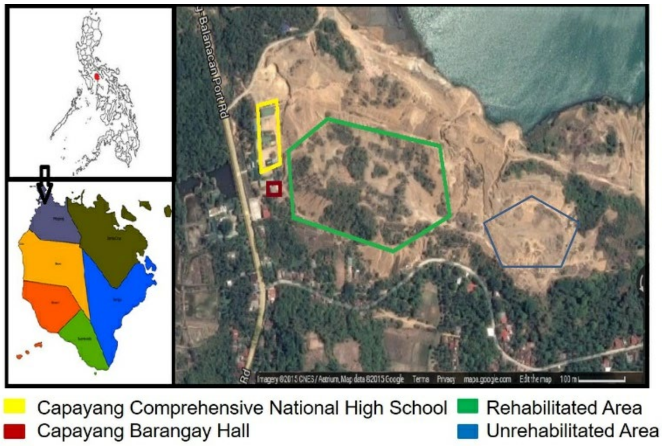

Fig. 1. Satellite map of the study area (Google Maps 2017)

Soil characterization. From each quadrat, soil sample, weighing approximately one (1) kilogram, was collected from a composite of 10 randomly collected soils. Samples were collected using a shovel around 10 to 20 cm deep in a 10 cm radius following sampling method of the DA-BSWM (Department of Agriculture-Bureau Soils and Water Management). Samples were placed in tied plastic bags and were labelled accordingly. Samples were then air dried, pulverized, sieved (2mm) and mixed thoroughly and were brought to the National Institute of Microbiology and Biotechnology (BIOTECH), UPLB for analysis (i.e. pH, organic matter (OM), P, and K).

Soil samples from each quadrat were also collected for bulk density analysis using canisters. This was done by removing 10 cm topmost part of the soil and canisters were pressed and hammered down until the topmost part of the canisters were filled up. Both ends were covered tightly and were labelled accordingly. Samples were brought to the College of Agriculture-Central Analysis Service Laboratory for laboratory analysis for bulk density. Soil samples for water holding capacity (WHC) were collected from each quadrat. This was done by clearing off the leaf and branch litter and dug 10-15 cm deep of soil using a shovel. Soil samples were placed in ziplock plastic bags labelled accordingly, and were brought to School of Environmental Science and Management (SESAM) Laboratory for analysis.

Soil physical and chemical analysis data were subjected to mean, standard deviation and student *t-test* descriptive statistical analysis, while t-Test for independent samples was used to test the significant differences between samples.

Plant diversity assessment. A calibrated string was placed to draw the boundaries of the quadrat. A quadrat measuring 20m x 20 m was used in counting vines and epiphytes. Within 20m x 20m quadrat, a subquadrat measuring 10 m x 10m was used in determining trees. Within this 20m x 20m quadrat, another subquadrat measuring 2m x 2m was used in assessing the shrubs, seedlings and saplings, another subquadrant measuring 1m x 1m was used for the inventory of grasses, ferns and seedlings. Establishment of subquadrats were randomly selected in each quadrat. The vegetation assessment was done following the methods by the Department of Environment and Natural Science-Environmental Management Bureau (DENR-EMB) and by Iskandar and Kotanegara (1995).

Plants in the sampling areas were identified, counted, measured and recorded. The diameter of trees was measured at 4.5 ft from the ground using a flexible ruler, while seedlings, saplings, and poles were measured at 10 cm above the ground. Grasses and ferns were measured by directly measuring the clumps and the area they covered.

Species richness per quadrat was based on the number of species recorded and Species Importance Value (SIV) was computed by getting the mean of relative frequency, relative dominance and relative density. Relative frequency is the ratio of the frequency of a species over sum frequency value of all species. Relative dominance is the ratio of dominance of a species over total dominance of all species. Relative density is the ratio of the total number of individuals of a species in all quadrats over total number of quadrats sampled.

SIV = relative frequency + relative density + relative dominance wherein:

$$\text{Relative frequency} = \frac{\text{number of sampled plots where a certain species is distributed}}{\text{number of total sampled plots}}$$

$$\text{Relative density} = \frac{\text{total number of a certain species in the total sampled plots}}{\text{number of species in the total sampled plots}}$$

$$\text{Relative dominance} = \frac{\text{sum total of DBH of a certain species in the total sampled plot}}{\text{sum total DBH of all species in the total sampled plots}}$$

Similarity of species in each quadrat was also determined by Bray-Curtis similarity matrix using Paleontological Statistics (PAST) version 1.68 software (Hammer et al. 2001).

RESULTS AND DISCUSSION

Soil characteristics. In spite of the amelioration added in the soil by the UPLB Bioremediation Team, only small changes were observed. Results of soil analysis showed no significant difference between the rehabilitated area and unrehabilitated area except for pH as shown by the *t-test* (Table 1). The overburden of excavation to uncover mineral ores raises environmental problems like loss of nutrient qualities and microbial activities. Metal-contaminated and metal-rich soils inhibit soil-forming process and plant growth (Favas et al. 2014). These rocks which are heterogenous in size were dumped, topping out the fertile or uncontaminated soil (Arsh 2017 and Yaseen et al. 2012).

Physical characteristics of the soil include bulk density and water-holding capacity. Bulk density for the rehabilitated area and unrehabilitated area were 1.25 m/cc and 1.41 m/cc, respectively. Both results fall under the classification described as suitable for plant growth according to USDA (2008). The water holding capacity (WHC) of the rehabilitated area and unrehabilitated area were 29.99% and 27.07%, respectively. The WHC was highly dependent on the amount of soil organic matter OM); such that, mined out area is expected to have low OM due to the absence of vegetation and other organisms that would contribute to its formation. The OM analysis in rehabilitated area was higher (0.50%) than the unrehabilitated area (0.39%). However, the low OM of soil in both areas is due to the nature of these dumps which are composed of unweathered rocks excavated during mining. These dumps covered the topsoil when these soil layers are excavated and stockpiled (Ssenku et al. 2014). Furthermore, the microorganisms inhabiting the topsoil are covered by the excavated rocks; thus, a longer period of time is needed to have a soil microbial activity similar with the topsoil (Ssenku et al. 2014).

Soil pH in both, rehabilitated and unrehabilitated areas were both acidic. However, the rehabilitated area was slightly more acidic than the unrehabilitated area (Table 1). Extracting copper, nickel and gold from mineral ores are highly associated with high amount of pyrites and other sulphides present in rock as wastes from mining operations. The spontaneous oxidation of minerals commonly known as pyrite which, when in contact with water or humid atmosphere, will react and release acidic effluents such sulfidic materials. (Bertland et al. 2017; Cuevas and Balangcod 2014).

Table 1. Mean soil physical and chemical characteristics (n= 6) in the mined out site under rehabilitated and unrehabilitated areas in Mogpog, Marinduque, Philippines. Values with different subscript letters are not significantly different (Student's *t-test*, $p > 0.05$)

Soil	**Rehabilitated area**		**Unrehabilitated area**	
Parameters	**Mean**	**SD**	**Mean**	**SD**
pH	4.13^{a}	0.15	4.80^{b}	0.14
OM **(%)**	0.50	0.14	0.39	0.04
N **(%)**	0.01	0.005	0.01	0.0
P (ppm)	68.50	9.68	77.50	0.50
K me/100g soil	0.23	0.04	0.25	0.05
Cu (ppm)	314	90.74	604	386
WHC (%)	29.99	0.18	27.07	0.08
BD	1.25	3.62	1.4	2.55

Degraded soils such as mined-out areas have very low essential nutrients (Favas et al. 2014). Similar results were obtained in our study. The macronutrients, N and K, in both rehabilitated and unrehabilitated areas areas were low (Table 1). Limited N in the soil can be attributed to the high Cu concentration which negatively affects the microbial activity, including the nitrogen fixation by microorganisms (Domingo and David 2014; Ssenku 2014). Low amount of K in the soil may be due to its solubility which makes them prone to leaching (Bradshaw 1997). Phosphorus content (rehabilitated area: 68.5 ppm and unrehabilitated area: 77.5 ppm) shows that both areas have exceeded the amount needed for plant growth according to the paper of Kruse (2007). This can be attributed to phosphorus fixation which is highly dependent to pH, where acidic soils increase mineralization compared to basic soils (Rodriguez and Fraga 1999). The Cu concentration in the rehabilitated area was much lower than in the unrehabilitated area. Soils with high Cu content allow only tolerant plants to grow (Chen 2000). High amount of Cu was still recorded from mined out rock waste dump even after mineral extraction. The difference in Cu content in both areas can be attributed to the rehabilitation efforts wherein rehabilitation species accumulated Cu in its roots, stems, leaves and seeds (Aggangan et al. 2015; Cadiz et al. 2010; Fontanilla and Cuevas 2010; Lange et al. 2016). Low soil pH directly and indirectly facilitated absorption of Cu. Moreover, low pH makes Cu more soluble for plant uptake (Ghosh 2015).

Plant diversity assessment. Plant inventory was done to determine the species diversity and species importance value (SIV) of the mined out site in Mogpog, Marinduque. Laurila-Pant et al. (2014) stated that plant diversity is acknowledged as basis for a healthy ecosystem. It favors and benefits the environment, as well as the plant species in the area. Each plant contributes distinctive root structure and adds residues to the soil. Plant diversity influences the composition and number of soil microorganisms that produce different variety of root exudates (Cadiz et al. 2012*;* Harantova et al. 2017, Llamado et al. 2013*;* Soderberg et al. 2002 as cited by Chen et al. 2008*)*. It protects and improves water availability of the soil and it also supports and provides habitat for larger organisms (Glaesner et al. 2014).

Table 2 lists the plant species in the course of rehabilitation. Plants listed under the first column were plants observed in 2006 (i.e. before the start of the rehabilitation efforts) and were considered the pioneer species. These include *Acacia auriculiformis*, *Davallia solida*, *Nephrolepis sp., Saccharum spontaneum*, and *Tremna orientalis* (Cadiz et al. 2012). The second column were four tree species used for the rehabilitation by the Bioremediation Team in 2007; namely, *Jatropha curcas, Pterocarpus indicus, Bauhinia purpurea and Cassia spectabilis* the species (Cadiz et al. *2012*), and the last column shows the species which were observed during the period (2016-2017) covered by the present study. These plant species were not present during the initial establishment of rehabilitation strategies. These recruited plant species were *Passiflora sp., Clitorea ternatea, Centrosema sp., Merremia tridentata, Melothria pendula, Psidium guajava, Leucaena leucocephala, Chromoaena odorata, Breynia vitis-ideae* and *Morinda sp.*

Table 2. Plant species in the mined-out sites in the course of the rehabilitation of the mined-out sites conducted in Mogpog, Marinduque.

Existing vegetation prior to rehabilitation	Species used for rehabilitation	Recruited plant species
Tremna orientalis	*Cassia spectabilis*	*Passiflora sp.*
Saccharum spontaneum	*Pterocarpus indicus*	*Clitorea ternatea*
Nephrolepis sp.	*Jatropha curcas*	*Centrosema sp.*
Davallia solida	*Bauhinia purpurea*	*Merremia tridentata*
		Melothria pendula
		Psidium guajava
		Leucaena leucocephala
		Chromolaena odorata
		Breynia vitis-ideae
		Morinda sp.

This indicates that aside from the species used in the rehabilitation, there were newly established plant species in the rehabilitated area. This also connotes that the rehabilitation efforts may have nurtured the seeds brought by wind or animals, such as birds, that led to the establishment of recruitment species.

Table 3 shows the mean Species Importance Value (SIV) under the rehabilitated area and the unrehabilitated area. The highest SIV (32.75) was noted in *A. auriculiformis* under the rehabilitated area. On the other hand, *S. spontaneum* had the highest SIV (58.90) under the unrehabilitated area and was also higher than the mean SIV of the same species under the rehabilitated area. The results indicate that grasses predominate under the unrehabilitated area, while more diverse vegetation was observed under rehabilitated area. Grasses can dominate marginal and open land areas more successfully than other species. Furthermore, grasses are more effective in adapting in mined-out areas because of their ability to tolerate and adapt to low soil nutrient at the same time take advantage of wide open space of mined-out area which provides high opportunities to capture sunlight. Similarly, grasses occupy the early stage of succession and seedlings or young trees occupy the latter stage (Harantova et al. 2017; Prafulla and Uniyal 2011). Similar observation was noted by Cuevas and Balangcod (2014) in non-grazed advanced seral stage (Cuevas and Balangcod 2014).

However, *S. spontaneum* was still the species with the second highest SIV under the rehabilitated area. Similar observation was noted by Harantova et al. (2017) and Prafulla and Uniyal (2011) where a transitional stage occurs from grass to trees. Consequently, the rehabilitation species serve as nurse species that support and facilitate the growth of other species (Sudarmaji and Hartati 2016). *Saccharum. spontaneum, A. auriculiformis* and *Nephrolepis sp.* were among the species recorded in the area in 2006, prior to rehabilitation activities. These species are widely known to have roots which are heavily colonized and infected with myccorhizal fungi (Agganan et al. 2015). The presence of mycorrhizal colonization increases plant tolerance to heavy metal contamination. This explains their tolerance and proliferation in the copper rich waste dump. In addition, the high SIV of *A. auriculiformis* can be explained by its ability to survive in in hospitable sites. They are fast growing and drought resistant. Although it is an exotic species, it is commonly used in reclaiming wasteland areas, including decommissioned mining sites. In addition, *A. auriculiformis* is a legume of the family Fabaceae and its presence in the area can help improve the quality of the soil through its nodule-containing nitrogen-fixing bacteria. Moreover, its pods are wide, flat, hard and twisted in irregular coils that are initially green which turn to brown and open upon ripening. Its black seeds hang out on strings of yellow aril to attract birds which in turn carry seeds that increase survival in the mined-out area. *S. spontaneum* is a perennial grass and is commonly found along riverbanks, roadsides and railroads. It grows on fertile soil but also found to grow in sandy soils and wastelands. It is capable of propagating vegetatively, and or through seeds which can be dispersed by wind (Yadav et al. 2016; Mani 2013). Furthermore, its ability to adapt to any environment and easy seed dispersal makes it easy for this species to establish itself even in mined-out areas.

Table 3 also shows the low SIV of plants that were planted during rehabilitation. The species that were considered pioneers had the second highest SIV under the rehabilitated area and the unrehabilitated area. This observation is similar with the findings of Harantova et al. (2017) and Prafulla and Uniyal (2011) which showed that after eight (8) years of restoration of the mined-out site, the planted species were still present. However, these species have been replaced by higher successional species after 23 years. Furthermore, the growth of the latter successional species may have occurred originally in the area prior to mining activities or could have occurred in the neighboring areas (Hanief et al. 2007; Mudraka et al. 2016).

Table 3. Mean species importance values (SIV) of plants in the mined out site in Mogpog, Marinduque, Philippines.

	Mean SIV	
Species	**Rehabilitated Area**	**Unrehabilitated Area**
Acacia auriculiformis	**32.75**	10.01
Saccharum spontaneum	23.94	**58.90**
Davallia solida	20.49	31.08
Nephrolepis sp.	9.57	-
Pterocarpus indicus	3.84	-
Melothria pendula	2.61	-
Psidium guajava	0.99	-
Jatropha curcas	0.94	-
Bauhinia purpurea	0.77	-
Leucaena leucocephala	0.75	-
Breynia vitis-ideae	0.74	-
Morinda sp.	0.74	-
Chromoaena odorata	0.74	-
Passiflora sp.	0.54	-
Merremia tridentate	0.53	-
Centrosema sp	0.53	-
Clitorea ternatea	0.53	-

The percentage (%) cover based on basal area in the mined out sites is presented in Table 4. There were no existing vines and trees in the unrehabilitated area as compared with the rehabilitated site. It also shows that there were healthier and denser seedlings, saplings, shrubs in the rehabilitated area compared with the unrehabilitated area (Figs. 2 and 3).

In terms of percent cover, the unrehabilitated area has higher basal area than the rehabilitated site due to the higher percent cover by grasses in the former. However, trees, saplings and seedlings dominated the rehabilitated area. Unlike grasses that form clusters, trees, saplings and seedlings form one main trunk or stem. This explains why the unrehabilitated area has a higher percentage (%) cover. This parameter gives idea on density, growth and size of trees present in a given area. Using basal area for determining the percent (%) cover helps make cover assessment of plant growth more reliable since it is not affected by recent grazing history and seasonality (Cade 1997).

Table 4. Mean percent (%) cover based on basal area of plants under rehabilitated and unrehbilitated areas of the mined out site in Mogpog, Marinduque, Philippines.

Plant Habit	**Percent (%) Cover**	
	Rehabilitated Area	**Unrehabilitated Area**
Vines	present	0
Trees	0.11	0
Seedlings	0.28	0.02
Grasses	0.99	6.12
TOTAL (%)	**1.38**	**6.14**

Ecological patterns of plants in the mined out area. The plant species assemblage based on Bray-Curtis similarity matrix is presented in Fig. 4. It illustrates the level of similarity of plant species among sampling sites. The figure shows two major clusters separating the two areas having 10% similarity. Here, numbers 5 and 6 represent the unrehabilitated area while numbers 1, 2, 3 and 4 represent the rehabilitated area. The species in both areas have significantly low similarity and is therefore indicative of the influence of the rehabilitation methods employed. Within the two unrehabilitated areas (represented in Fig. 4 as lines 5 and 6), a 50% similarity was observed. Among the rehabilitated areas (represented in Fig. 4 as lines 1, 2, 3 and 4), area 4 has the least similarity with the other rehabilitated areas. However, there is a 60% similarity of area 4 with its subclusters 1 and 2. Copper content of this quadrat may also play an important role, since it is in this area where Cu content is least.

Fig. 2. Vegetation cover of the rehabilitated area located at the top most part of Consolidated Mines Incorporated (CMI) rock dumpsite in Mogpog, Marinduque, Philippines. February 15, 2016 (Photo credits: Katrine Mae B. Mante)

Fig. 3. Vegetation cover of the unrehabilitated area (area without intervention) located at the top most part of Consolidated Mines Incorporated (CMI) rock dumpsite in Mogpog, Marinduque, Philippines. February 15, 2016 (Photo credits: Katrine Mae B Mante).

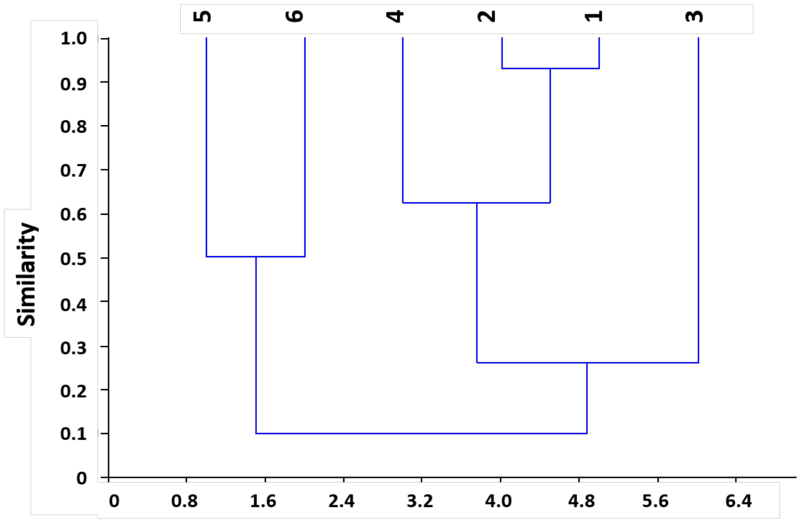

Fig. 4. Plant species assemblage based on Bray-Curtis similarity matrix.

CONCLUSION AND RECOMMENDATION

The result of the study showed that there was no significant difference in soil chemical analysis between rehabilitated and unrehabilitated area. However, the mean species richness was higher in the rehabilitated area than in the unrehabilitated area. Vegetation cover of the mined out rehabilitated area showed higher basal area for seedlings and saplings than the unrehabilitated area. Vines and trees were also present in the rehabilitated area but were absent in the unrehabilitated area. This showed that soil amendments used during the earlier rehabilitation efforts have helped increase the growth of other plant species. Cluster analysis showed that there was 90% difference between rehabilitated area and unrehabilitated area in terms of vegetation. Rehabilitated area showed higher basal areas of vines, trees, saplings and seedlings than the unrehabilitated area since only grasses provided high basal area cover in this site.

Rehabilitation of mined out sites proved to be necessary and effective as indicated in the improvement of vegetation cover and diversity. However, it takes time for the soil to improve since the area is all exposed rocks. Weathering of rocks takes a long process and the production of detritus plant materials also takes time. It is necessary that long time monitoring of rehabilitated areas be made to come up with management strategies that could help improve rehabilitation efforts.

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