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ARTHROPOD RECOLONIZATION IN REHABILITATED MINED-OUT NICKEL MINES IN SURIGAO PROVINCE, PHILIPPINES

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Abstract

Arthropods inhabiting the soil and litter are eliminated during mine extraction particularly in nickel mining. In this operation, the topsoil and the associated vegetation are stripped off. Planting of Mangium (Acacia mangium) and Agoho (Casuarina equisetifolia) is generally done to rehabilitate the mined-out areas in Caraga Region, Philippines. To monitor the ecosystem restoration in rehabilitated sites, the recolonization of arthropods was assessed. Sampling was conducted in sites where C. equisetifolia and A. mangium are planted and in the newly introduced ecobelt. In the 4-year old and 10-year old C. equisetifolia planting at Hinatuan Mining Corporation, arthropods have started to assemble in the soil and litter. In these sites, species of ground beetles, true bugs and ants are present, with the red ants predominating. In 1-year old C. equisetifolia, none was sampled yet since the litter fall is still very thin and the soil is not yet favorable to harbor soil-inhabiting arthropods. In the ecobelt where 1-year old mixed planting of tree and flowering plant species at Hinatuan Mining Corporation, 7 species of arthropods were collected. In Taganito Mining Corporation, soil-dwelling beetles, true bugs, flies and springtails have been collected from the rehabilitated sites. In the 1-year old ecobelt at Taganito Mining Corporation, only species of red ants and staphylinid beetles were collected. The copious growth of the nurse trees in areas rehabilitated for 4 years and older and in the ecobelt provided partial shading that possibly modified the microclimate that attracted the arthropods.

Keywords: *Recolonization; Arthropods; Mine rehabilitation; Nickel mining; Ecobelt*

Introduction

The soil and litter-inhabiting arthropods can be seriously disturbed during nickel extraction that adopts strip or surface mining technology. Strip mining is the common method to extract nickel where a huge amount of topsoil and overburden had to be removed along with the vegetation. The topsoil removal can disturb the soil quality, vegetation and associated faunal diversity. This leads to soil erosion where particles and associated minerals eventually reach the water bodies nearby and cause siltation. Hence, the government requires mining companies to rehabilitate the mined-out areas to restore the ecosystem and prevent siltation in adjoining water bodies.

Conserving a forest strip to buffer soil erosion and filter contamination is a natural way of mitigating the impacts of mining to interconnected ecosystems. With vegetation strategically

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located, chemical elements and sediments can be trapped thereby preventing these to reach agricultural systems, human settlements and the freshwater and marine ecosystems. In New Caledonia, one of the environmental protection measures in mining sites is the maintenance of buffer zones where vegetation is maintained to act as sediment traps and pollution control [1, 2]. I In China, a framework of spatial control planning and design of landscape elements for the purpose of managing and using mined-out areas is established. This is an important path to maximize landscape resources and to improve ecological function in mine closure areas [3]. The use of nickel hyperaccumulators which are native to the mining site is also viewed as an option in rehabilitating mined-out nickel areas [4, 5]. In the nickel mines in Caraga Region, the rehabilitation strategy in Australia for bauxite mine is adopted with the planting of tree species particularly Australian Pine Tree locally known as Agoho (*Casuarina equisitefolia* L.) and Mangium (*Acacia mangium* Willd.). However, in the Caraga Region, the replanting adopts a monoculture system where Agoho or Mangium is planted as a single species for several hectares of mined-out area. As such, there are still gaps that need to be addressed to come up with a comprehensive and strategic rehabilitation program in the nickel mines to reduce the environmental impacts particularly dust generation and siltation affecting the interconnected water bodies and settlement areas. Moreover, being a monoculture, there is very little diversity in plant height resulting to less vertical stratification that can influence the microclimate within. Likewise, with only a single species planted, limited amounts of litters can accumulate and influence nutrient cycling. This, in turn, influences the suitability of the habitat for the pioneering animals such as arthropods. In nickel mining where the soil quality needs to be restored to support ecosystem restoration, the arthropods that act as macrodecomposers in soil and litter need to be monitored. Thus to evaluate the effectiveness of the various approaches in nickel mine rehabilitation, arthropods that inhabit the soil and litter were sampled being known to be among the early colonizers.

Methodology

Study Area

The project was implemented in the nickel mines in Claver, Surigao del Norte and Hinatuan Island within the Hinatuan Passage at the northeastern part of Mindanao, Philippines. The mining areas are located at the northern tip of the Mt. Diwata Range, which is part of the Eastern Mindanao Biodiversity Corridor.

Revegetation in mined lands

Planting of *C. equisetifolia* and *Acacia mangium* was done by the mining company. Planting of the two species adopts the monoculture system with regular intervals of 2m x 2m distance.

In the ecobelt, different floral species were used. The different species were planted in strips for re-vegetation to assist natural regeneration. The trees include native timber tree species and fruit trees. Flowering plant species were also included to attract pollinators, which are important agents of dispersal. Planting was done in staggered manner, with the nurse trees planted first, followed by the flowering plants. The indigenous species were planted after the nurse trees have survived and have substantial canopy to cover.

Monitoring and evaluation of arthropod recolonization after mine rehabilitation

The condition of the ecosystem was monitored and assessed to determine the effect of rehabilitation efforts to the restoration of the ecosystem. Arthropods that inhabit the soil and litter were sampled to determine recolonization in the site. Two composite samples of soil and litter were collected from each selected rehabilitated site. The samples were brought to the laboratory for processing. These were placed in the Berlese funnel and the arthropods collected in the jar were then sorted, identified and counted per taxon.

Results and Discussion

Occurrence of soil and litter-dwelling insects in Hinatuan Mining Corporation (HMC)

Table 1 presents the relative abundance of arthropods in the rehabilitated mined-out areas at Hinatuan Mining Corporation (HMC). In the 4-year old and 10-year old Agoho, arthropods particularly insects have started to assemble in the soil and litter. Although the diversity of insects is very low, it already indicates that the rehabilitation of the plant community has started to encourage biodiversity by attracting fauna that feed on them. In plots where 4-year old and 10-year old Agoho grow, beetles, true bugs and ants are present, with the red ants predominating. In 1-year old Agoho, none was sampled yet since the litter fall is still very thin which is not adequate to cover the soil and change the microclimate. In addition, the soil is still compacted and not favorable yet to host soil-inhabiting arthropods. In the constructed ecobelt in Hinatuan Mining Corporation, composed of 2-year old mixed planting of tree species and flowering plant species, 7 species of insects have been collected from the experimental site. The profuse growth of the nurse trees provided partial shading to other species that probably modified the microclimate in the ecobelt thereby attracting insects that survived in the soil. There was no litter-dwelling insect sampled yet since the litter cover is so far still very sparse.

The vegetation existing in the rehabilitated areas are the potential factors that modify the microclimate of the ecosystem. The seasonal relationships of land use, urban plant cover and microclimate in the metropolitan of Phoenix, Arizona, USA was studied. The land use had the most pronounced effect on microclimate during the early morning hours of summer, with agricultural and residential land uses having the highest relative humidities, dew point temperatures, and NDVI, and the lowest air temperatures [6]. The study importance of urban trees in alleviating the heat island effect in a hot and humid summer was reported [7]. They stated that the tree cooling effect was found to be strongly related to the built form geometry. In all the studied cases, the thermal effect of the tree was found to depend mainly on its canopy coverage level and planting density in the urban street and little on other species characteristics.

The abundance of arthropods in the 10-year old Agoho rehabilitated area is higher than in the 4-year old Agoho and the newly established ecobelt. In the 10-year old Agoho, a total of 83 individuals were collected for the 4 quarterly assessments conducted. This is followed by the abundance of arthropods in 4-year old Agoho with 61 individuals. The arthropod abundance in the newly constructed ecobelt was very low at 26. The results indicate that abundance and diversity of arthropods inhabiting the soil and litter are dependent on the quality of the habitat. The amount of litter and shading that modified the microclimate of the site are probably the factors influencing diversity of arthropods. Canopy cover is indeed one of the primary attributes influencing colonization patterns of arthropods in restored vegetation [8]. Plantings that are widely spaced may facilitate some colonization by rainforest arthropods.

Mites of the Oribatid family were collected in both the 10-year old and 4-year old Agoho. The amount of litter cover in these plots may be the factor considering that time has been longer to allow for litter accumulation. Oribatids are the most common mites that can be seen associated with forest litters. In the newly established ecobelt, the plants are still very sparsely distributed thus the litter accumulation is still very light. Besides, the ecobelts are spaced far apart from each other, leaving some open areas vulnerable to heating during dry spell and erosion during rainy days. Red ants of the Family *Formicidae* are the more common species sampled from all the sites. So far, only three species of ants have been sampled. The existence of ants as pioneering faunal species in rehabilitated mine lands may imply its importance as an indicator species for ecosystem restoration. The ant bio-indicator concept include providing of baseline data in pre-development situations; monitoring ecosystem recovery following land rehabilitation, monitoring degree of ecosystem degradation, and the understanding of faunal composition and status of conservation areas [9]. Similarly, a report that at mine sites undergoing restoration, ant communities show clear successional patterns [10]. In this study, over the first five years following disturbance, species richness of ants rapidly increases before stabilizing, with the type of ants recolonizing the site determined by various aspects of ecosystem development. Thus in the mine rehabilitation program in the nickel industry in the Philippines, the existence of ants can be significant in the monitoring system to measure the impact of the rehabilitation efforts to ecosystem restoration.

Occurrence of soil and litter-dwelling insects in Taganito Mining Corporation (TMC)

The relative abundance of arthropods occurring in the various habitats represented by the various rehabilitated mined-out areas in Taganito Mining Corporation is presented in Figure 3. In the soil and litter of the mixed vegetable area used as a demonstration farm of TMC for bio-intensive gardening, arthropod populations started to gather. The shade provided by the plant community and the fertilization of plants, as part of the crop management, have probably rendered the ecosystem favorable to soil and litter-inhabiting insects. Soil-dwelling beetles, true bugs, flies and springtails were collected from the site. Soil-dwelling insects, particularly collembolans (springtails) are important in the nutrient cycling in the soil.

Table 1. Relative abundance of soil and litter-inhabiting arthropods in rehabilitated nickel mines in Hinatuan Mining Corporation, Surigao Province, Philippines

Sampling Stations	Sample	Order	Family	No. of Individuals Per Taxon
	Sample 1	Hymenoptera	Formicidae1	29
		Coleoptera	Staphylinidae	5
		Coleoptera	Scarabaeidae	4
			Staphylinidae	2
			Scydmaenidae	1
		Hymenoptera	Formicidae2	32
HMC (10-year old Agoho)		Acarina	Oribatidae	20
	Sample 2		Blattodea	1
		Hemiptera	Cicadellidae	9
		Coleoptera	Scarabaeidae	11
			Staphylinidae	8
		Hymenoptera	Braconidae	1
		Diptera	Cecidomyiidae	3
		Acarina	Oribatidae	12
Abundance				**138**
	Sample 1	Hemiptera	Cicadellidae	2
		Coleoptera	Scarabaeidae	6
			Staphylinidae	9
			Cucujidae	1
HMC (4-year old Agoho)		Hymenoptera	Formicidae	36
		Diptera	Sepsidae	1
		Acarina	Oribatidae	9
	Sample 2	Hemiptera	Anthocoridae	4
			Cicadellidae	1
		Hymenoptera	Formicidae	29
		Coleoptera	Scarabaeidae	6
Abundance				**104**
	Sample 1	Hemiptera	Cicadellidae	2
		Coleoptera	Scarabaeidae	12
		Hymenoptera	Formicidae	16
HMC (Ecobelt)	***Sample 2***	Hemiptera	Cicadellidae	3
		Hymenoptera	Formicidae	15
		Coleoptera	Staphylinidae	4
		Diptera	Phoridae	11
		Hymenoptera	Formicidae	14
Abundance				**77**

In the 2-year old mixed planting (ecobelt) in TMC experimental site, only species of red ants and staphylinid beetles were collected. The slow growth of the mixed plant species due to the lack of organic matter in the soil prevented the development of wide canopy to modify the microclimate of the area. This makes the ecosystem not conducive to the survival of many organisms, especially soil-inhabiting insects. Ants have been the dominant arthropods considering the number of individuals collected from the site. They can be used as indicators of ecosystem restoration in rehabilitated mined land [11]. The existence of these insects can be useful in the monitoring of the ecosystem restoration after rehabilitation of the mined-out areas.

Table 2. Relative abundance of arthropods occurring in the various rehabilitated mined-out areas of Taganito Mining Corporation, Surigao Province, Philippines

Sampling Stations	Samples	Order	Family	No. of Individuals Per Taxon
	Sample 1	Hemiptera	Cicadellidae	6
		Coleoptera	Staphylinidae	6
		Diptera	Psychodidae	5
		Collembola	Entomobryidae	4
		Hemiptera	Cicadellidae	2
TMC Area 1 (Mixed vegetable)		Hymenoptera	Formicidae	24
	Sample 2	Hemiptera	Cicadellidae	8
		Coleoptera	Staphylinidae	6
		Coleoptera	Cucujidae	2
		Hymenoptera	Formicidae	26
		Diptera	Sepsidae	2
		Acarina	Oribatidae	26
Abundance				**115**
	Sample 1	Hemiptera	Cicadellidae	4
		Coleoptera	Staphylinidae	8
		Hymenoptera	Formicidae	23
	Sample 2	Coleoptera	Staphylinidae	10
TMC Area 2 (Mixed vegetable)			Cucujidae	3
		Hemiptera	Cicadellidae	4
		Coleoptera	Staphylinidae	4
			Cucujidae	2
		Hymenoptera	Formicidae	22
		Collembola	Isotomidae	12
		Diptera	Psychodidae	1
Abundance				**93**
	Sample 1	Hemiptera	Cicadellidae	4
TMC Area 3 (Ecobelt)		Hymenoptera	Formicidae	14
		Coleoptera	Staphylinidae	3
	Sample 2	Coleoptera	Staphylinidae	7
		Hymenoptera	Formicidae	21
Abundance				**49**
	Sample 1	Hymenoptera	Braconidae	1
TMC Area 4 (Ecobelt)		Hymenoptera	Formicidae	27
	Sample 2	Coleoptera	Staphylinidae	6
		Hymenoptera	Formicidae	12
Abundance				**46**

Diversity of soil and litter-inhabiting arthropods

In this study, the results indicated that the early colonizers in rehabilitated mined out areas include soil fauna. The area after 10 years since rehabilitation started using *C. equisetifolia* has higher arthropod diversity that those newer ones (Figure 1). The species richness in area planted to *C. equisetifolia* after 10 years is higher than those in areas that were rehabilitated later. Nonetheless, the existence of the early colonizers may boost the soil quality thus increase in faunal diversity can be expected. Invertebrate soil fauna may boost secondary succession and local plant species diversity [12]. Soil fauna from the mid-succession stage had the strongest effect and that this finding might improve the restoration and conservation of plant species diversity. The influence of invertebrate soil fauna on succession has been documented; however, little attention has so far been given to this aspect.

There are several factors that influence soil arthropod diversity. In mined out areas in Caraga Region, where the soil is almost totally exposed to the sun and direct impact of rain during rainy days, soil arthropods cannot easily assemble. Thus in sites that are rehabilitated for only 4 years or 2 years, the diversity of arthropods was still very low (Figure 1). Other factors such as latitude can also influence diversity. However, the native arthropod community diversity decreased with increasing latitude [13].

Arthropod recolonization in highly disturbed lands may take longer especially in nickel mine where the topsoil and vegetation are totally removed. Thus recolonization can be expected when vegetation has also slowly rejuvenated. Initial recolonization and dominance was achieved by species that were either rare in the adjacent native vegetation or had immigrated from other disturbed sites [14]. Species richness and diversity showed an increase during the first three years following revegetation, but then declined over the next 3 years. The trophic structure on reclaimed mine sites was dominated by omnivores, insect-carrion feeders, predators, and fungivores, whereas the undisturbed site's beetle fauna was dominated by omnivores, predators, and herbivores. With a very high variability of the trends in diversity in reclaimed mined lands, they concluded that recovery of these lands will require a significant length of time and may not ever yield a biodiversity similar to those of the premining stage resulting from the serious disturbance.

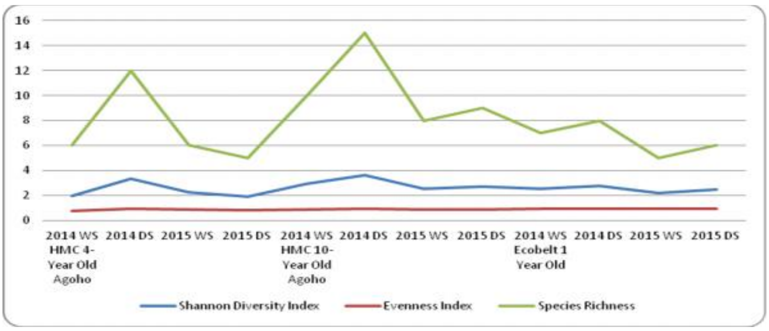

Fig. 1. Diversity of arthropods occurring in the various rehabilitated mined-out areas of Hinatuan Mining Corporation during the wet and dry season in 2014-2015

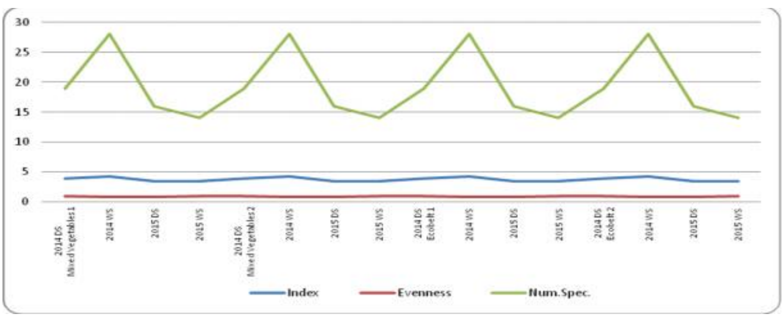

Fig. 2. Diversity of arthropods occurring in the various rehabilitated mined-out areas of Taganito Mining Corporation during the wet and dry season in 2014-2015

Ecosystem restoration monitoring is necessary after mined land rehabilitation. This aids in assessing the extent of rejuvenation in the disturbed areas and serves as basis in land rehabilitation protocol. In many studies, ants are regarded as important indicators in ecosystem restoration. However, conservation managers are left with little guidance as to if, when, and how ants can be used to assess conservation activities [15]. Thus they outline areas where ants provide valuable information for management-based monitoring: (a) to detect the presence of invasive species, (b) to detect trends among threatened or endangered species, (c) to detect trends among keystone species, (d) to evaluate land management actions, and (5) to assess long-term ecosystem changes. Practical considerations are likewise discussed when designing a monitoring framework for ants, including appropriate methods, taxonomic resolution for sampling, and spatial and temporal scale. Ant species richness and equitability are potential status indicators of the soil arthropod community and equitability can be used to monitor ecosystem change [16]. The number of taxa, collembolan and oribatid species diversity and community structure were the most sensitive mesofaunal parameters for evaluating the soil restoration treatments [17].

Conclusion

The soil in mined out areas of nickel mines has been badly disturbed due to the removal of the topsoil and the associated vegetation. Thus the soil quality needs to be improved to support ecosystem restoration. The early colonizers such as arthropods that act as macrodecomposers in soil and litter are essential for evaluating the effectiveness of the various approaches in nickel mine rehabilitation. Ants and beetles are the most common arthropods that recolonize disturbed areas after rehabilitation. Ants, due to their adaptation, are usually the early colonizers. Their populations in newly rehabilitated areas are important guides in determining ecosystem restoration.

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