Phytosuccession and Phytosociology of Plants in Ino-Capayang Mined-out Area for Possible Phytoremediation Activities in Marinduque

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***Abstract*—Mining is a destructive activity. A lot of earth and rocks are removed in a mining site before the precious metals are extracted. In search for plants that can help in revegetating former minefields this study analyzed the phytosuccession and phytosociology of species in the former Ino-Capayang mined-out area. Twenty-nine, 1x1m quadrats were laid in a belt-liked manner in a selected *green island* of the area. Plants for each quadrat were counted, identified, classified and the biodiversity, richness and evenness indices were computed. Shoot samples of the abundant species were collected and subjected to Cu^{+2}, Pb^{+2} and Zn^{+2} content analysis using AAS. Results revealed 37 plant species belonging to 25 families. The most abundant species were in the peripheries of highly acidic areas, such as ferns (*Ptyrogramma sp.*, *Nephrolepis sp.*, *Sphenomeris sp.*), grasses (*Imperata sp*. and *Saccharum sp.*), and herbs and shrubs of *Chromolaena odorata*, *Lantana camara*, and *Stachytarpheta jamaicensis*. These were classified as *pioneers* in the mined-out area. They also showed high levels of heavy metals in the shoots as compared to those plants found in mining-free area of the province. Therefore, these plants have potentials in revegetating former minefields, like that of Ino-Capayang.**

***Keywords*—mined-out area, phytoremediation, phytosociology, phytosuccession.**

I. Introduction

The Philippines is one of the most mineral rich places of the world, due to its tectonic formation [1], [2]. It is 5th in mineral deposits worldwide, 3rd in gold, 4th in copper, 5th in nickel chromite and 12th in nickel deposits [2]. The country has also deposits of silver, platinum, palladium and uranium that are needed in electronics industry [3], [4]. These mineral deposits are located in biodiversity rich areas and geohazard zones for landslides, typhoons and volcanoes [1]. Marinduque Island is one of the heavily mineralized areas for gold, copper and iron [4], thus two mining companies operated in the province since the 60s up to late 90s, using the destructive open-pit mining. One example was that of Marcopper Mining Corporation (MMC), where about 220 million tons of soil and rocks had been removed and dumped to extract one million tons copper from 1969 to 1991 [1], [4]. Once mining happened, the abandoned minefields or mined-out areas prevailed for years, due to acid mine drainage (AMD) [5]. The acidic nature of AMD, the dissolves heavy metals and the crystallized salts make revegetation of the area difficult to happen [6]. Continuous soil erosion of the contaminated soil affects the agricultural lands nearby [7] and the heavy metals contaminate bodies of water [8]. The mined-out area left by Consolidated Mines Incorporated (CMI) in Ino-Capayang, Mogpog that operated from July 1968 to August 1980, is a concrete evidence of environmental disaster in the province [9], [10].

In 2001, less than 30% of the area is covered with vegetation, excluding the mine-made lake created by the operation [10]. At present, the area is still barely covered with vegetation, with mean pH value of 3.34 ± 045 [9].

It is believed that understanding *phytosuccession* and *phytosociology* of species in the *green islands* of the former minefields can help in revegetating the area. Based on ecological parlance, *phytosuccession* is the establishment of a plant community (*green island*) in a disturbed area [11], while *phytosociology* is the distribution, relationship and interaction among plant species and soil microbiota, like fungus in the area under study [12], [13]. Plants adapted to such areas are called *metallophytes* or metal tolerant plants that have capacities to form communities (*green islands*) acidic and heavy metals rich areas [14], [15]. These plants can be tapped for *phytoremediation* of mined-out areas [16], [17], [18].

This study aimed to identify the plants in the CMI *green island*, classify them, measure their biodiversity, richness and evenness indices, and measure the amount of Cu^{+2}, Pb^{+2}, and Zn^{+2} in the shoots of the most abundant species.

II. Methods

A. Study Area

The CMI mined-out area is located between Ino and Capayang, municipality of Mogpog, approximately 3.72 km road from the town proper (Fig. 1). CMI operated in two ore bodies, such as the Isaw-Pili and Ino-Capayang, which applied an open-pit bench-type of mining. It created an oval, bowl-shaped pit, the Ino-Capayang Mine-made Lake. CMI has copper concentrate tenement area of 1,259.32 ha, but due to low price of copper in the market and high production cost, the company was closed in August 1980 [19]. Its oblong-shaped pit measured 0.724 km east-west and 0.526 km north-south is filled with water almost like a lake [20], [21].

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A belt transect of 29 quadrats measuring 1x1m was set in a chosen area with no human introduced plant species. The plants in each quadrat were counted individually and in clumps for the case of grasses and ferns [22].

Fig. 1. Location of the Ino-Capayang CMI mined-out area. Inset is the google map of the study area.

B. Plant Identification and Classification

The counted and collected plants in the transect were taken with pictures and kept in Ziploc plastic bags and identified using published journals, books and authorities with knowledge in plant taxonomy, forestry and agriculture. The study followed the works of [23], [24], [25], [26], [27].

C. Plant Abundance and Biodiversity Indices

Shannon-Wiener Biodiversity Index (*H*) was used to characterize the plant species diversity in the selected *green island* in the study area. This accounts for both abundance and evenness *E* of the plant species present. The typical value of the *H* max index may range from ≤ 1.5 (low species) to ≥ 3.5 (high species) [28]. Evenness (*E*) was determined for the proportional distribution of the plant species and this generally assumes a value between 0 and 1 with values approaching 1 (0.8 to 1.0) means complete evenness [29]. The proportion of species (*i*) relative to the total number of species (p_i) was calculated and then multiplied by the natural logarithm of this proportion (ln p_i). The resulting product was summed across species and multiplied by -1.

$$H = \sum pi \ln pi$$

$$E = \frac{H}{Hmax}$$

$$Hmax = \ln N$$

where *N* is the total number of species

D. Plant Distribution, Grouping and Phytosociology

The population distribution of the plant species was put in a table for analysis of the plants that are connected to each other. They were plotted to find out their distribution in the 29 quadrats. A cross-sectional diagram to show the plants distribution grouping into ferns, grasses, shrubs and trees was made based from the plotted distribution. Some plants were uprooted to look for presence of fungi, especially *Arbuscular mycorrhizae* (AM) in their root system. AM occurs in all soil ecosystem even in polluted soils [30]. Studies revealed that the presence of mycorrhizal fungi or inoculating a heavy metal hyperaccumulating plant is good for revegetating polluted soil [31]. AM helps in immobilizing heavy metals and other pollutants and absorbing the soil nutrients that are required by the plants [32], which at the same time nourishing the nearby plants in the community [33]. This analysis gave the phytosociological relations between them.

E. Test for Cu^{+2}, Pb^{+2} and Zn^{+2} in Abundant Plant Shoots

Shoots from the most abundant plant samples were collected from the study area were the 29 belt quadrats were set. The shoots were gathered randomly from the plants as composite samples. They were washed under running tap water to remove dirt; air dried and then separated the shoots into species. Shoots of similar plant samples were gathered in areas not affected by mining and these plants were gathered in Tumagabok, Boac, in the interior part of the province. All samples were packed in Ziploc plastic prior to atomic absorption spectrophotometric (AAS) analysis for Cu^{+2}, Pb^{+2} and Zn^{+2} contents in Intertek Testing Services in Makati City, Metro Manila, Philippines. All analyses done followed that of Association of Official Analytical Chemists [34].

III. Results and Discussion

A. Plant Identification and Classification

There were 37 plant species identified in the established belt transect (Table 1). They were represented by 25 families of plants.

The most represented families with plant species were Fabaceae, represented by five species, followed by Apocynaceae (3) and Phyllanthaceae (3). The rest are represented by two and one species per family.

Plants under Fabaceae are nitrogen-fixing plants and therefore can survive such kind of harsh environment for their growth [15], [16].

The species with highest number were *Ptyrogramma sp.* (28), a type of fern, followed by *Stachytarpheta sp.* (17); an herb, *Nephrolepis sp.* (15), another type of fern; *Chromolaena sp.* (14), an herb; *Imperata sp.* (14) and *Saccharum sp.* (12), both grasses. These plants formed hardy communities along the acidic and metal-laden soil peripheries of the *green island*, thus considered as *pioneers.*

B. Plant Abundance and Biodiversity Indices

Table 2 shows the Shannon-Wiener biodiversity index (*H*) of the 29 quadrats, which ranges from 0.02 (quadrat 20) to 0.21 (quadrats 1 and 5) and 0.19 (quadrats 2, 4 and 29). Each quadrat does not have diverse plant species as they are limited from 1-7 species. In quadrat 20 there is only one plant, a big

Leucaena or ipil-ipil tree, which almost covered the whole area of the quadrat.

TABLE 1: IDENTIFICATION, CLASSIFICATION AND RESPECTIVE COUNTS OF PLANTS IN THE 29 QUADRATS.

Plant species	Family name	Type	No.
Ptyrogramma calomelanos	Pteridaceae	Fern	28
Stachytarpheta jamaicensis	Verbenaceae	Herb	17
Nephrolepis cordifolia	Lomariopsidaceae	Fern	15
Chromolaena odorata	Asteraceae	Herb	14
Imperata cylindrica	Poaceae	Grass	14
Saccharum spontaneum	Poaceae	Grass	12
Sphenomeris chinensis	Lindsaeaceae	Fern	9
Lantana camara	Verbenaceae	Shrub	9
Calamus sp.	Arecaceae	Climber	7
Morinda citrifolia	Rubiaceae	Shrub	6
Ardisia sp	Myrsinaceae	Tree	4
Cassia grandifolia	Fabaceae	Tree	4
Desmodium heterophyllum	Fabaceae	Herb	4
Ficus septica	Moraceae	Shrub	4
Leea philippinensis	Leeaceae	Shrub	4
Leucaena leucocephala	Fabaceae	Tree	4
Tabernaemontana pandacaqui	Apocynaceae	Shrub	4
Acacia mangium	Fabaceae	Tree	3
Tabernaemontana subglobosa	Apocynaceae	Tree	3
Macaranga tanarius	Euphorbiaceae	Tree	3
Alstonia scholaris	Apocynaceae	Tree	2
Bischofia javanica	Phyllanthaceae	Tree	2
Breynia sp.	Phyllanthaceae	Shrub	2
Fleuggea leucopyras	Phyllanthaceae	Shrub	2
Lygodium circinnatum	Lygodiaceae	Climber	2
Scirpus grossus	Cyperaceae	Grass	2
Trema orientales	Cannabaceae	Tree	2
Cyperus javanicus	Cyperaceae	Grass	1
Ficus ulmifolia	Moraceae	Tree	1
Ipomoea sp.	Convulvolaceae	Climber	1
Ludwigia sp.	Onagraceae	Herb	1
Lepisanthes sp.	Sapindaceae	Tree	1
Litsea glutinosa	Lauraceae	Tree	1
Muntingia calabura	Muntingiaceae	Tree	1
Passiflora foetida	Passifloraceae	Climber	1
Pithecollubium dulce	Fabaceae	Tree	1
Psidium guajava	Myrtaceae	Shrub	1
N = 37 species			193

The highest *H* index is 0.214 (quadrat 1), 0.206 (quadrat 5), 0.199 (quadrat 4), 0.190 (quadrats 2 and 29). All these values were below the typical *H* max index of ≤ 1.5 (low species). The evenness distribution ranges from 0.00 (quadrat 20) to 0.19 (quadrat 1). All the quadrats have low species indices and the species are not evenly distributed. This may be due to the weak adaptive capacity of the plant species to the acidic nature of the soil and the presence of heavy metals as brought by the continuous formation of AMD, due to exposed ores that scattered the area.

Quadrats 1, 2 and 29 (the end quadrat) were dominated with ferns, such as *Ptyrogramma*, *Nephrolepis* and *Sphenomeris* species, while quadrats 4 and 5 are dominated by grasses, *Lantana* and *Stachytarpheta* species. The inner quadrats were dominated by shrubs and trees with few species of climbers like *Calamus* and *Ipomoea*.

It is an indicator that the studied *green island* is still in the process of phytosuccession after more than three decades. The highly vascular plants, like the trees and shrubs will take a long period of time before they dominate the altered land.

Ecological studies have also revealed the existence of specific plant communities, like ferns and other endemic floras, which have adapted on soils contaminated with elevated levels of Co^{+2}, Cu^{+2}, Pb^{+2}, Ni^{+2}, and Zn^{+2} [14], [15].

TABLE 2: BIODIVERSITY INDEX, RICHNESS AND DISTRIBUTION EVENNESS OF PLANTS IN THE 29 QUADRATS.

Quad-rat	No. species	Total No. Plants	H	*H* max (richness)	*E* (evenness)
1	3	17	0.213995	1.0986122	0.194786
2	4	14	0.190315	1.3862943	0.137283
3	5	9	0.142949	1.6094379	0.088819
4	7	15	0.198547	1.9459101	0.102033
5	5	16	0.206433	1.6094379	0.128264
6	7	10	0.153373	1.9459101	0.078818
7	5	7	0.120297	1.6094379	0.074745
8	3	3	0.064726	1.0986122	0.058916
9	2	2	0.047352	0.6931471	0.068315
10	4	4	0.080339	1.3862943	0.057952
11	2	2	0.047352	0.6931471	0.068315
12	4	4	0.080339	1.3862943	0.057952
13	4	4	0.080339	1.3862943	0.057952
14	4	4	0.080339	1.3862943	0.057952
15	7	8	0.131948	1.9459101	0.067807
16	3	3	0.064726	1.0986122	0.058916
17	4	4	0.080339	1.3862943	0.057952
18	2	2	0.047352	0.6931471	0.068315
19	7	7	0.120297	1.9459101	0.061828
20	1	1	0.027267	0.0000000	0.000000
21	4	5	0.094643	1.3862943	0.068271
22	2	4	0.080339	0.6931471	0.115905
23	4	4	0.080339	1.3862943	0.057952
24	3	3	0.064726	1.0986122	0.058916
25	2	8	0.131948	0.6931471	0.190360
26	3	8	0.131948	1.0986122	0.120104
27	4	8	0.131948	1.3862943	0.095180
28	2	3	0.064726	0.6931471	0.093380
29	3	14	0.190315	1.0986122	0.173232
	37	193	0.108605	1.2358331	0.086904

Note: *H* max (richness) ≤ 1.5000 low species, ≥ 3.5 high species
E (evenness) values approaching 0.8000 to 1.000 means complete evenness

C. Plant Distribution, Grouping and Phytosociology

In Table 2, and as discussed previously, there was an uneven distribution of plants in the 29 quadrats. The peripheries of the *green island* were characterized as highly acidic and heavy metals laden areas. Crystallized salts were observed along the peripheries.

Fig. 2 shows the most peripheral quadrats (1 and 29) were dominated by *Ptyrogramma* ferns. This means *Ptyrogramma* is the most hardy *pioneer* species that can stand highly acidic and metal laden conditions of the *green island*. Quadrat 2 showed the association between *Ptyrogramma*, *Nephrolepis* and *Sphenomeris* with few herbal plants *Stachytarpheta*, while Quadrat 28 had the association of *Ptyrogramma* and *Nephrolepis*. Quadrats 3 showed association of ferns, herbs and grasses, like *Imperata* and *Saccharum*, while 27 had *Ptyrogramma*, grasses *Cyperus* and *Imperata* and herb *Desmodium*. *Lantana*, a scrambling shrub was found in association of *Saccharum*, *Stachytarpheta*, and *Chromolaena*, both herbs, in quadrat 4. These were found also stunted saplings of highly vascular plants, like *Morinda* and *Ficus*.

At the other end, quadrat 26 was observed with association of *Imperata* and herb *Desmodium* and *Chromolaena*. Quadrat 25 has *Saccharum*, *Stachytarpheta*, *Chromolaeana* and *Lantana*.

This means that the identified ferns, grasses and herbs survive and adapt to the most edaphic conditions of the area or quadrats with high acidity and presence of crystallizing salts of heavy metals.

The inner quadrats were dominated by highly vascular plants of trees, which are mainly members of Fabaceae that are nitrogen fixing plants. The taller trees were associated with climbers, like *Calamus*, *Ipomoea* and *Passiflora*.

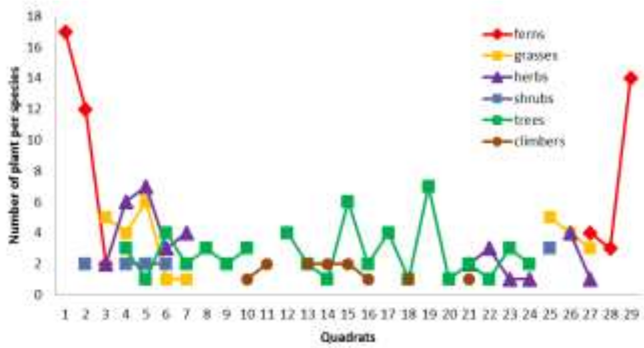

Fig. 2. Number, distribution and association of plants in the quadrats.

Fig. 3 shows the cross-sectional arrangements of the plants in the studied *green island*.

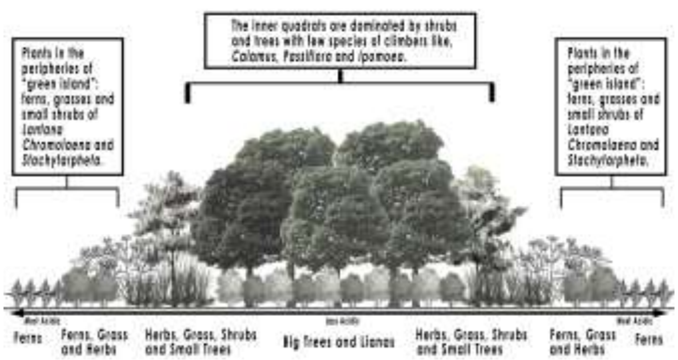

Fig. 3. Cross section of the studied *green island* showing the phytosociology of species in the area.

The acidic peripheries were dominated by ferns, then grasses, herbs and shrubs, and the less acidic inner quadrats were dominated by trees with some climbers. *Leucaena* first appeared in quadrat 8 and at the other end at quadrats 24 and 23. Other highly vascular plants, like *Morinda* and *Ficus* first appeared in quadrats 4 and 23. *Tabernaemontana*, *Breynia* and *Ardisia* in quadrats 4, 23 and 24 repectively.

These plants lived in association with each other with network of *Arbuscular mycorrhizae* (AM) hyphae observed in all the quadrats in the roots and rhizomes of the identified plants. The same matt of fungi were observed in the decomposing leaves and twigs of the plants, especially in the inner quadrats.

Studies revealed that AM helps in sequestering necessary nutrients for growth of the plants and immobilizing the heavy metals by chelating [33] them at the same time and transporting them from roots to shoots [30].

This phytosiciological association of plants, the *pioneers*, the AM harbouring plants and the networks of mycorrhizal hyphae that formed among plants, help the colonization of the inner quadrats with highly vascular plants.

D. Test for Cu^{+2}, Pb^{+2} and Zn^{+2} in Abundant Plant Shoots

Table 4, shows the difference in the amount of test heavy metals in the shoots of the plant samples. It is obviously shown that high levels of heavy metals were detected in those plants samples collected in the Ino-Capayang mined-out area.

The eight most abundant species, which are majority called *pioneers* accumulated high levels of Cu^{+2} with the exemption of *Nephrolepis*, a fern species. The highest metal accumulator was *Ptyrogramma*, for all the three tested metals, followed by *Lantana*, *Saccharum* and *Stachytarpheta*.

TABLE 4: HEAVY METAL CONTENTS OF THE PLANTS' SHOOTS FROM THE STUDY AREA IN COMPARISON WITH MINING UNAFFECTED AREA.

Plants	Cu^{+2}		Pb^{+2}		Zn^{+2}	
	ICM	MUA	ICM	MUA	ICM	MUA
P. calomelanos	67.04	11.56	1.34	ND	28.15	10.07
S. jamaicensis	33.17	4.77	1.28	ND	10.11	4.32
N. cordifolia	5.33	0.17	0.21	0.02	1.27	1.04
C. odorata	26.18	5.04	1.09	ND	13.48	1.19
I. cylindrica	15.48	3.08	2.13	ND	4.33	ND
S. spontaneum	36.44	1.53	0.80	ND	5.17	1.29
S. chinensis	28.21	2.69	1.23	0.01	3.32	0.21
L. camara	37.15	6.83	0.06	0.04	14.97	1.25

Note: All values are in mg kg^{-1} ND = not detected
ICM – plant shoots from Ino-Capayang Mined-mined Out Area
MUA – plant shoots from Mining Unaffected Area (Tumagabok)

Majority of the species are accumulators of Cu^{+2} and Zn^{+2}. The low accumulations of Pb^{+2} may be related to the fact that lead is not a common heavy metal in the soil of the study areas.

IV. Conclusion

The identified fern species, grasses, and the specific plants, like *Lantana camara*, *Stachytarpheta jamaicensis* and *Chromolaena odorata* are classified as *pioneers* in phytosuccession in the area. These are the plants that can survive the harsh environment of former minefields that are acidic and heavy metals rich.

As they grow in the peripheries of the area and expand into floral communities, the soil is made less hazardous for the vascular plants to follow or invade the land.

These plants form a network of AM hyphae within the roots and rhizomes of associated plants and form matt of fungi in decaying leaves. They enhance the uptake of heavy metals from root to shoots and nourish the associated plants with nutrients for them to adapt to the contaminated environment. As the *pioneers* prepare the edaphic environment of the peripheries, other plants harbour AM that help the vascular plants to evade the middle of the *green island*.

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