Vol. 7 January 2016
CHED Accredited Research Journal, Category A-1
Print ISSN 2094-5019 • Online ISSN 2244-0461
doi: http://dx.doi.org/10.7828/ajob.v7i1.864

Asian Journal of Biodiversity
This Journal is in the Science Master Journal List of
Thomson Reuters (ISI) Zoological Record

Rapid Assessment of Plant Diversity in Ultramafic Soil Environments in Zambales and Surigao del Norte, Philippines

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ABSTRACT

This study covers the vegetation composition and diversity in two heavy metal sites with distinct climatic and edaphic environments in the Philippines, Zambales, and Surigao del Norte in the northern and southern regions, respectively, Tree density and basal area were higher in Zambales than in Surigao del Norte. Species diversity, however, was higher in Surigao del Norte site (H'=1.1071) than in Zambales, which may be attributed to high water and nutrient availability and unique geologic formations. Soil properties also varied, with higher organic matter concentration in Surigao del Norte. Twenty-one out of 35 taxonomic families in both sites were common in serpentine soils. Nine families were recorded to have a large number of individuals on both sites. A total of 11 species were known metallophytes of which four are Ni hyperaccumulators and seven are endemic to both sites. These Ni hyperaccumulators have a high potential for phytoremediation, phytostabilization, and rhizofiltration. However, due to the scarce information on Ni hyperaccumulators, conservation statuses of most of them are unknown. Agricultural interference, site destruction and excessive mining are some of the factors contributing to the diminishing fate of metallophytes. Thus, it calls for its prioritization in biodiversity conservation.

Keywords: Plant diversity, ultramafic, nickel hyperaccumulators

INTRODUCTION

The Philippines contains a diverse range of forest formations. These forest formations occur over different substrates that are often associated with distinct vegetation (Fernando *et al.* 2008). Ultramafic soils host a unique habitat of plant communities. Ultramafic refers to igneous or metamorphic rocks which contain less than 45% silica and high concentrations of Mg, Cr, Co and Ni, and low concentrations of P, K, and Ca (Proctor 2003). Poor productivity, high rates of endemism and vegetation type distinct from those surrounding areas are collective traits of this soil type (Bani *et al.* 2010). Metallophytes are the natural component of vegetation in this type of substrate (Fernando *et al.* 2013). These species are able to grow in soils with high levels of metals and metalloids and usually show high amounts of heavy metals such as Ni and Co compared to plants in other soil types (Alford *et al.* 2010; Bani *et al.* 2010). However, some metallophytes called hyperaccumulators have the capacity to accumulate higher concentrations of metallic or metalloid elements (Ginocchio and Baker 2004; van der Ent *et al.* 2012). For example, nickel hyperaccumulators are recognized to have Ni concentration at 1000 μg/g in its above-ground tissue (van der Ent *et al.* 2013). Metallophytes also have the potential for phytoremediation especially in mined-out areas, phytomining, phytostabilization, phytovolatilization, phytoprospection, and rhizofiltration (Chaney *et al.* 1997; Ciarkowska and Fajerska 2008; Fernando *et al.* 2013). Several studies have already identified or described plants that thrive in heavy metal-enriched soils and mined-out sites in Europe (e.g. Reeves and Brooks 1983; Punz 1995; Korycinska 2006; Holyoak and Baker 2004), South America (e.g. Ginocchio and Baker 2004), Africa (e.g. Malaisse *et al.* 1999), and Asia (e.g. Rotkittikhun *et al.* 2006; Claveria *et al.* 2010; van der Ent *et al.* 2013; Fernando *et al.* 2013, 2014; Quimado *et al.* 2015). The degradation of forests has become one of the serious environmental impacts of mining (Kobayashi 2009; Fernando *et al.* 2013). Thus, information on species composition, diversity indices, and related data about metallophytes are important for their conservation. This can also be useful in mining industries and policy making for the conservation of native metallophytes for phytoremediation.

OBJECTIVES OF THE STUDY

This study aimed to: 1) identify and compare metallophytes present in two ultramafic sites in the Philippines; and 2) determine their current composition and diversity.

MATERIALS AND METHODS

Description of the Study Sites

Two mining sites were selected for this study, namely; DMCI Mining Corporation (DMC) in Zambales and Central Luzon and Taganito Mining Corporation (TMC) in Surigao del Norte in northeastern Mindanao. DMC is located in Central Luzon at 15° 42' 0" N and 120° 4' 1" E and an elevation of 657 m. It has a Type I climate with the distinct dry season from November to April and wet during the rest of the year. Average annual rainfall in Zambales is 287.58 mm (PAG-ASA 2014). TMC is located at 9° 30' 0" N and 125° 53' 0" E of Claver, Surigao del Norte with an elevation of 55-76 m. Claver falls under Type II climate with no definite dry season and a pronounced maximum rainfall was occurring from November to January. Surigao del Norte has an average annual rainfall of 304.32 mm (PAG-ASA 2014).

Vegetation Sampling

A 20 x 20 m plot divided into eight 5 x 5 m quadrats was randomly established at each site. Diameter at breast height and a total height of all species (≥ 1 cm diameter) was recorded. Samples were also collected as voucher and herbarium specimens.

Soil Analysis

Rhizosphere soil samples inside the plots were collected, air-dried, and stored in polyethylene bags. Soil analysis to determine organic matter (OM) content, pH, cation exchange, and calcium and magnesium contents were done at the Agricultural Systems Cluster, University of the Philippines Los Baños.

Data Analysis

Shannon-Wiener (H') and Simpson's (D) diversity indices were computed using the BioDiversity Pro software. Species richness and evenness were also determined for each of the plots. Tree density and basal area were also computed. H' was computed as $H' = \Sigma p_i \ln p_i$: where p_i is the proportion of individual species *i*. On the other hand, D was computed as $D = [N (N - 1)]/\Sigma n_i (n_i - 1)$: where N is the total number of individuals of all species and n_i is the number of individuals of species *i*.

RESULTS AND DISCUSSION

Soil properties in two sites are summarized in Table 1. Low pH in both sites was recorded. However, contrasting results in OM and Mg/Ca quotient were observed between the sites. Surigao del Norte site had higher OM than Zambales site but the latter had lower Mg/Ca quotient compared to the former site. Basal area and species composition were different in both sites (Table 2). In the Zambales site, trees have larger diameter compared to those in the Surigao site. Although average diameter is high in Zambales, its basal area was only slightly higher compared to that of the Surigao site. The number of species and individuals in the Surigao site is high, which compensates the relatively smaller diameter of its trees. However, significant differences in the basal area and tree density in between sites were found. Most of the diversity indices used such as evenness, Shannon-Wiener index (H'), and Simpson's index (D) were also significantly different in both sites. There were 35 families with 393 individuals in Claver, Surigao del Norte, and Sta. Cruz, Zambales (Figure 1). Nine families, seven in Surigao del Norte and two in Zambales, dominated the two sites. Several species considered to be obligate and facultative metallophytes were found in both sites (Table 3, Figure 2). Among the facultative metallophytes, *Phyllanthus erythrotrichus* in Zambales, and *P. securinegoides* in Surigao del Norte are known Ni hyperaccumulators; two other species, *P. curranii* (Zambales) and *P. ramosii* (in Surigao del Norte) are non-nickel hyperaccumulators (Quimado *et al.* 2015; Table 3). The percentage of endemism is high in areas with serpentine soils and is more generally distinct in tropical to warm temperate countries (Rajakaruna and Baker 2006; Baker *et al.* 2000).

Several factors can affect the plant diversity of ultramafic environments. In serpentine soils, the indirect relationship was found between metal solubility and pH. Heavy metals such as Ni, Cu, Cd, and Cu are more soluble at lower pH level. In closed woody vegetation, a lower pH caused by humic decay under moist conditions may increase the availability of metals in the soil. However, despite containing a higher exchangeable amount of soil metal, the vegetation community was considered more evolved and structured suggesting that heavy metal content in soils not be a limiting factor for serpentine vegetation (Chiarucci *et al.* 1998). A more evolved and structured vegetation community is characterized by relatively low total species richness but with large canopy layer. In the present study, despite the few vegetation in the Surigao site, the large number of individuals helps improve the moist condition for humic decay to maintain a low pH. Many studies showed Mg/Ca quotient as an important limiting factor of plant growth (Baker *et al.* 1992; Roberts and Proctor 1992;

Ghasemi *et al.* 2013). Serpentine soils typically have high Mg/Ca quotient or low Ca: Mg mol ratios (< 0.1), and high Mg content in soils affects the availability of other nutrients such as N, P, and K, for plants. However, Chiarucci *et al.* (1998) reported that high OM increase have available N and P. In the present study, plants found in the Zambales site with higher Mg/Ca quotient in the soil compared to the Surigao site were possibly more subject to stress. Higher OM in the Surigao site may also have contributed to the number of species in the said site. Water stress, nutrient deficiency, and soil water retention rather than soil metal content were found to be more significant in the vegetation structure differences (Chiarucci *et al.* 1998; Proctor *et al.* 1999). This observation in water availability affecting vegetation structure was also noticed in Surigao del Norte and Zambales sites where differences in species composition and diversity occur (Table 2). The abundant rainfall in Surigao del Norte may have contributed to its high species diversity. The latter site also experiences distinct dry seasons in a year. The periodic drought which can cause groundwater loss may affect vegetation development and number (Chiarucci *et al.* 1998). Abiotic stress particularly inter-annual fluctuations of rainfall especially along arid regions negatively affect species diversity (Aronson and Shmida 1992). However, while the differential impact on rainfall is agreed, a combination of several factors such as soil type and land-use system can affect the extent of its impact to vegetation (Dahlberg 2000). In California plant communities, for example, soil fertility and climatic productivity positively affect plant growth and beta diversity (Fernandez-Going *et al.* 2013).

Another factor which may contribute to the differences in plant communities between sites is the geologic complexes in the Philippines. Differences in the substrates resulting from geologic formations affect species composition and diversity (Fernando *et al.* 2008). Yumul (2007) proposed four belts of ophiolite formation in the Philippines recognizing the ultramafic complexes' ages and possible lithospheric sources. In this classification, the Surigao del Norte and Zambales sites belong to Belt 1 and Belt 3, respectively. This suggests that an earlier formation of ophiolites in the former site than in the latter could create differences in the plant composition. Over 400, nickel hyperaccumulators across different plant families have already been described in 2012 (van der Ent *et al.* 2013). A total of 27 out of 35 families in both sites (17 in Surigao and 10 in Zambales) are known to be present in serpentine soils elsewhere in the tropics (Proctor 2003; Rajakaruna and Baker 2004; Baker *et al.* 2000; Ginocchio and Baker 2004; Malaisse *et al.* 1999). Families such as Phyllanthaceae, Flacourtiaceae, Goodeniaceae and Myristicaceae present in both sites are known to have metal-accumulating taxa (Baker *et al.* 2000; Proctor 2003; van der Ent *et al.* 2013).

Obligate metallophytes such as *Buchanania*, *Dillenia*, and *Decaspermum* species are strictly ultramafic species, which occur only in areas with extreme physical and chemical properties. Facultative metallophytes, which include *Callicarpa* and *Scaevola*, are species with specific tolerance to metals and may be found in non-metal enriched areas (Baker *et al.* 2000). The use of these indigenous nickel hyperaccumulators in phytomining and phytoremediation will not only aid in the cleanup of environmental pollutants but also encourage conservation of indigenous and critically endangered species (Chaney *et al.* 1997; van der Ent *et al.* 2013; Wong 2003; Prasad 2005). Non-metallophytes belonging to families Dipterocarpaceae and Thymeleaceae were also present in the sites. However, in Palawan, Philippines, these families only occur in greywacke and not in serpentinized peridotite (Proctor 2000). A large number of endemic metallophytes is attributed to its extremely restricted habitat and its tolerance to serpentine soils (Baker *et al.* 2000; Brady *et al.* 2005). Furthermore, the endemism of these species serves as evolutionary genetic trade-offs of their inability to thrive and compete with other plants in non-serpentine soils (Brady *et al.* 2005).

Table 1. Soil Properties per Plot in Zambales and Taganito

Soil Properties	**Site**	
	Zambales	**Surigao del Norte**
pH	6.56 ± 0.08	6 ± 0.26
OM (%)	2.03 ± 0.66	5.81 ± 4.25
CEC (me/100g soil)	30.53 ± 3	24.7 ± 6.12
EC (uS/cm)	91.6 ± 24.78	353 ± 122
Ca (me/100g soil)	5.07 ± 0.87	6.86 ± 2.79
Mg (me/100g soil)	11.87 ± 1.06	6.31 ± 1.74
Mg/Ca	2.34	0.92

Table 2. Averages of Tree (≥ 1 cm dbh) Density, Basal Area, Number of Species, Shannon and Simpson's Indices, and Number of Regenerations on 20 x 20-m Plots in Zambales and Surigao del Norte

	Zambales	**Surigao del Norte**	**P-value**
Tree (≥ 1 cm dbh) density	5.45	5.25	
Basal area	0.22	0.21	*
Average diameter (cm)	3.36	2.62	*
No. of species	23	55	
No. of individuals	106	287	
Evenness	0.8797	0.9167	**
Shannon-Wiener Index (H')	0.6500	1.1071	*
Simpson's Index (D)	0.1976	0.0775	**
Simpson's Index (1/D)	8.2075	18.2761	NS

Values are significantly different at P=0.001 (*), P=0.01 (**), and not significant (NS).

Most if not all of the nickel hyperaccumulators identified in both plots have not yet been assessed for the IUCN Red List (Table 3). Considering the small size of the plot for this study, it is possible that a huge number of endemic metallophytes that may be critically endangered or undiscovered yet have not been included in the assessment. In view of this, metallophytes also have a high potential for absolute extinction. Several factors in the absolute extinction of heavy-metal vegetation such as human interference leading to eutrophication, alkalinization, heavy-metal sites targeted for extraction, and ecological succession have been identified by several authors (Baker *et al.* 2000; Lucassen *et al.* 2008; Erskine *et al.* 2012; Jacobi *et al.* 2011). As these metallophytes face these threats, there is a need for the prioritization of these species in the biodiversity conservation efforts.

CONCLUSIONS

The two forests over the ultramafic soil in the Philippines showed distinct differences in terms of floristic composition and diversity. Abundant rainfall, soil fertility, and age of the formation of ophiolite complexes are possible factors dictating differences in plant communities in Zambales and Surigao del Norte sites. A large number of endemic Ni hyperaccumulators observed in both sites is a characteristic common to metal-enriched soils. Endemism in these soils is attributed to factors such as habitat restrictions and physiological and evolutionary mechanisms. These metallophytes have the potentials to be used in mining industries for rehabilitation and phytoremediation and, therefore, these plant resources must be conserved.

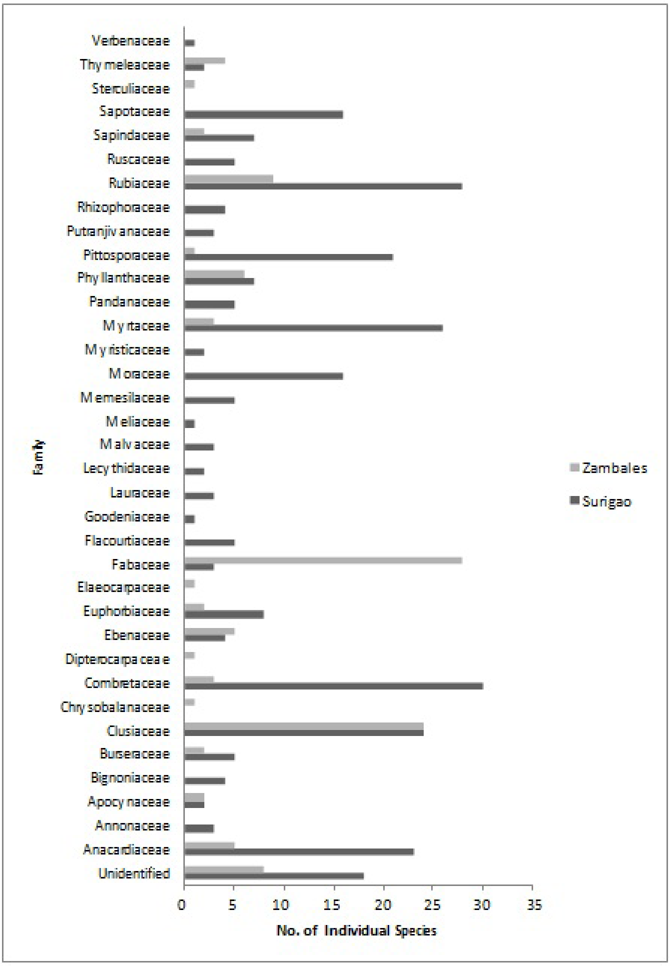
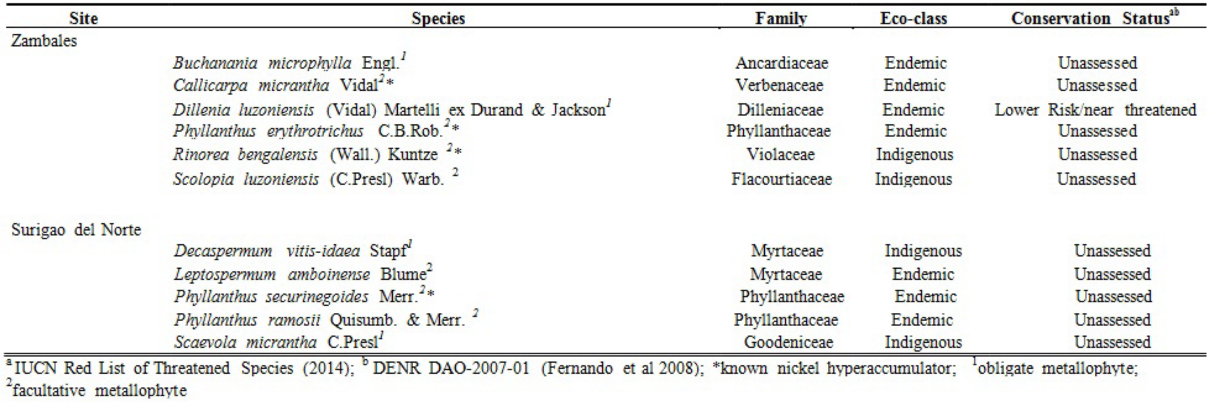


Figure 1. Number of Individual Species per Family in the 20 x 20 m Plots in Zambales and Surigao del Norte.

Table 3. Conservation Status and Eco-class of Sample Metallophytes in Surigao del Norte and Zambales Plots



Site	Species	Family	Eco-class	Conservation Status[ab]
Zambales				
	Buchanania microphylla Engl.[1]	Ancardiaceae	Endemic	Unassessed
	Callicarpa micrantha Vidal[2]*	Verbenaceae	Endemic	Unassessed
	Dillenia luzoniensis (Vidal) Martelli ex Durand & Jackson[1]	Dilleniaceae	Endemic	Lower Risk/near threatened
	Phyllanthus erythrotrichus C.B.Rob.[2]*	Phyllanthaceae	Endemic	Unassessed
	Rinorea bengalensis (Wall.) Kuntze [2]*	Violaceae	Indigenous	Unassessed
	Scolopia luzoniensis (C.Presl) Warb. [2]	Flacourtiaceae	Indigenous	Unassessed
Surigao del Norte				
	Decaspermum vitis-idaea Stapf[1]	Myrtaceae	Indigenous	Unassessed
	Leptospermum amboinense Blume[2]	Myrtaceae	Endemic	Unassessed
	Phyllanthus securinegoides Merr.[2]*	Phyllanthaceae	Endemic	Unassessed
	Phyllanthus ramosii Quisumb. & Merr. [2]	Phyllanthaceae	Endemic	Unassessed
	Scaevola micrantha C.Presl[1]	Goodeniceae	Indigenous	Unassessed

[a] IUCN Red List of Threatened Species (2014); [b] DENR DAO-2007-01 (Fernando et al 2008); *known nickel hyperaccumulator; [1]obligate metallophyte; [2]facultative metallophyte

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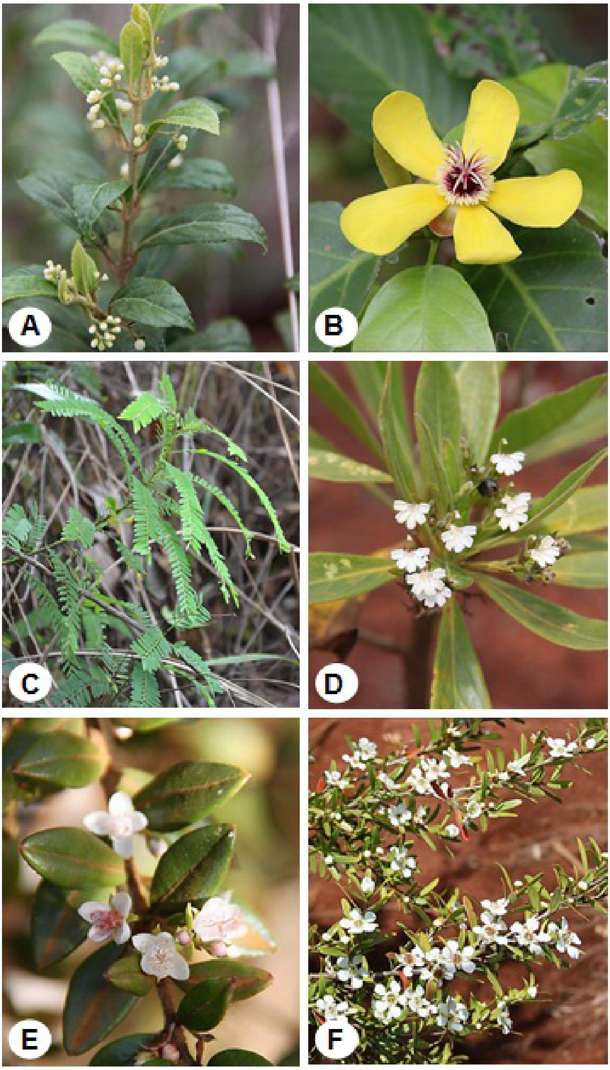

Plate 1. Metallophytes and Hyperaccumulators from Zambales and Surigao. A. *Callicarpa micrantha*, B. *Dillenia luzoniensis*, C. *Phyllanthus erythrotrichus*, D. *Scaevola micrantha*, E. *Decaspermum vitis-idaea*, F. *Leptospermum amboinense.*