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Native Metallophytes on Ultramafic Wooded Grassland in Sta Cruz, Mindoro Occidental, Philippines: Insights Into Phytostabilization and Forest Restoration

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ABSTRACT

The native metallophytes species are the optimum choice to restore degraded areas on ultramafic soil. However, a limited restorative floristic survey on the wooded grassland of Mindoro Occidental had been reported. Four 20 m x 20 m plots were established to rapidly assess the plant diversity of a wooded grassland on ultramafic soil in Sta. Cruz, Mindoro Occidental, Philippines. Diversity index (H`), relative density, relative dominance, and importance value (IV) were computed. Physicochemical characteristics and heavy metal contents of the soil in the site were analytically determined. We identified 43 morpho-species of plants belonging to 25 families. Thirty-six of the morpho-species identified are Philippine natives and typically grow on ultramafic forests. Nine species out of the top 10 trees with the highest IV are native ones, with *Buchanania arborescens* Blume as the most dominant. The estimate of Relative Cover (%) also showed native species. Poles and sapling dominated the area, suggesting that active regeneration is taking place. Further, 72.94% of the ground cover were represented by tree flora recruits (e.g., *B. arborescens*, *Alstonia macrophylla*). The sites have overall moderate diversity (H` index of 2.7). The soil contains a high amount of Nickel, Chromium, Iron, and Manganese. There were no Nickel hyperaccumulators but 22 native species showed Aluminum and Silicon hyperaccumulation. Therefore, the study revealed that the surveyed area is home to important metallophytes that have the potential for phytostabilization and reforestation.

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1. INTRODUCTION

Ultramafic soils are characterized by a high amount of Nickel, Chromium, Cobalt, Iron, and Magnesium (Cardace & Meyer-Dombard, 2014; Echevarria, 2018). 'Ultramafic' is roughly synonymous to 'serpentine' (Proctor, 2003) and has been used interchangeably in papers on tropical ultramafic ecology (van der Ent et al., 2019). The characteristics of ultramafic soil determine the plant species that can thrive on it; hence, there is a large number of unique or endemic species restricted to ultramafic areas (Garnica-Díaz et al., 2022). In the Philippines, plant diversity research although geographically limited, had been done on ultramafic forest of Mt Bloomfield, Palawan (Proctor, 2003), Mt Guiting guiting, Sibuyan (Proctor et al., 1998), Surigao del Norte (Ata et al., 2016; Sarmiento, 2018), and Dinagat (Lillo et al., 2019). However, data on the vegetation of ultramafic soil is poorly investigated in both grassland and forest ecosystems in the country (Proctor, 2003). A rapid assessment of plant diversity on understudied ultramafic areas in the Philippines will provide insights into phytostabilization and forest restoration possibilities of areas at risk, such as those subjected to mining exploration and infertile grasslands.

One of these understudied ultramafic areas is found on the western side of Mindoro Island, the Amnay Ophiolitic complex, which is made up of belts of ultramafic rocks (Perez et al., 2013; Yumul Jr et al., 2009). Ophiolites and their ultramafic rocks are hosts to different Chromium and Nickel deposits and Tupaz et al. (2020) reported high NiO (up to 15.6 wt%) and CoO (up to 11.3 wt%) concentrations in Mindoro Philippines. Ultramafic or serpentine soil (from weathering of parent material ultramafic rocks) belongs to the group of ferromagnesian siliceous rocks characterized by nutrient deficiency (especially Calcium) and high concentrations of potentially phytotoxic trace elements (Galey et al., 2017). The pH of tropical ultramafic soil ranges from acidic to ultrabasic (Galey et al., 2017; Proctor, 2003), hence, plants growing in such a substrate normally contain basiphilous and/or calcifugal taxa of high taxonomic and ecological importance. These native species not only can tolerate metal toxicity but also survive and reproduce (Baker & Whiting, 2008). Some of them are obligate, i.e. restricted to ultramafic soils; many others are facultative, i.e., able to thrive on both ultramafic and normal soils. It is one of the reasons why diversity assessment of native serpentine species has gained much interest in many countries.

Native ultramafic/serpentine species, called metallophytes, have the potential for phytostabilization (Chathuranga et al., 2015) of degraded serpentine lands and forest restoration of mined ultramafic areas (Baker & Whiting, 2008; Erskine et al., 2012). However, there is an urgent need for more floristic surveys and botanical explorations in ultramafic areas to determine native species potentially suitable for species conservation and restoration technologies such as phytoextraction, phytostabilization. Thus, we conducted a rapid plant diversity assessment of an area in Sta. Cruz, Mindoro Occidental to provide insights into native tree species conservation, and phytostabilization towards restoration of grassland on ultramafic soil. This is a part of our field studies on the metallophyte flora of the Philippines and associated nickel hyperaccumulators in the region (Ata et al., 2016; Fernando et al., 2020; Fernando et al., 2014; Fernando et al., 2013; Quimado et al., 2015). Specifically, this paper aims to: a) locate the native plants growing on the wooded grassland, b) determine the tree diversity indices, and c) classify the located native plants based on endemism, heavy metal content, and conservation status.

2. MATERIAL AND METHODS

2.1. Study area

The study area was within the municipality of Sta. Cruz, Mindoro Occidental (at 3°7′12″N, and 120°51′0″E) on flat to gentle slopes (Fig. 1). The area forms part of what is referred to in Mindoro Island as 'parang' vegetation (Gonzalez et al., 2000) or 'partially wooded grassland' (De Alban, 2009), and such areas, including grasslands, occur extensively in Mindoro Occidental. The Mindoro Occidental or western Mindoro highlands is sparsely covered with trees except for patches of *Pinus merkusii* forests due to longer dry season, poor soil, and fire-prone climax grassland (Gonzalez et al., 2000). Exotic species of trees such as *Acacia auriculiformis, Eucalyptus sp., Gmelina arborea,* and *Swietenia macrophylla*, were planted to reforest some portions of the study sites in Sta Cruz.

The climatic conditions in this part of the island belong to Type I of the Coronas climate classification with a pronounced dry season from November to April, and wet during the rest of the year. The average annual rainfall is 2,000 mm while the temperature range from 16.44 to 30.7 °C (https://mimaropa.neda.gov.ph/; De Alban (2009)).

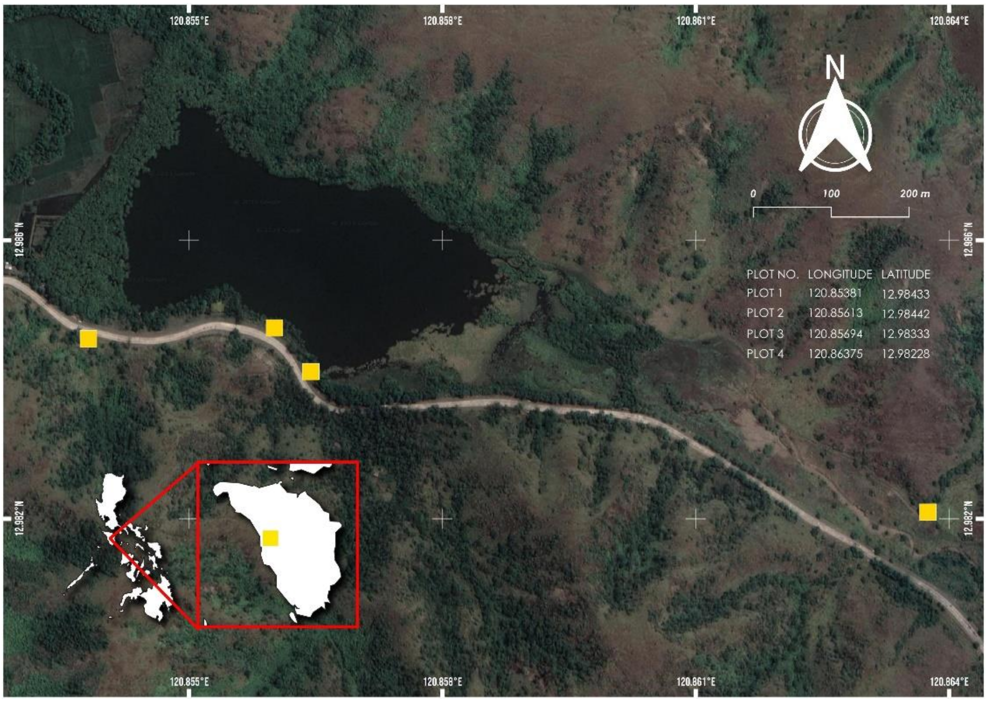

Figure 1. Location of the sampling plots in Sta. Cruz, Mindoro Occidental, Philippines

2.2. Procedures

2.2.1. Vegetation Survey

The survey was conducted in March 2020. Four 20 m x 20 m quadrat plots with nested 5 m x 5 m and 1 m x 1 m plots were established at intervals of between 75 and 1100 m, with elevation ranging from 10 m to 50 m above sea level along a WNW to ESE direction (Fig. 1). The Shannon-Wiener (H`) diversity index, relative density, relative dominance, and importance value of the plants were computed for each plot. Soil samples were also collected from each plot to determine the soil physical-chemical characteristics and heavy metal content. Plot 1 (12°59′3.60″N, 120°51′13.70″E) was established on a partially wooded grassland at 50 m asl, while plot 2 (12°59′3.90″N, 120°51′22.1″E) was near the Karindan lake, where *Acacia auriculiformis* was planted. Plot 3 (12°59′0.00″N, 120°51′25.00″E) was adjacent to an old nursery area at 10 m asl. This nursery has old planting stocks of *Acacia auriculiformis, Gmelina arborea*, and *Swietenia macrophylla*, all non-native species, frequently used in government tree planting projects. Similar to plot 1, plot 4 12°58′56.20″N, 120°51′49.50″E was also laid out in a partially wooded grassland at 11 m asl located near a dry stream bed. All plots including Plot 4 are on serpentine soil. The areas between plot 3 and plot 4 included just the same variety of grass and lacked poles and saplings. The map of the sampling plots was generated using QGIS 3.16.

The nested quadrat sampling technique was employed to provide foundational knowledge about the site as to the existing state of the flora and the physical conditions of the sites. The diameter at breast height (dbh) of trees with $\geq$1 cm in diameter was recorded and the plants were identified. The inventory of plants classified as shrubs, poles, and saplings inside the 5 m x 5 m quadrat was recorded, while percentage cover of understorey species (grasses and other plants with < 1 cm height) inside the 1 m x 1 m quadrat was determined. Voucher specimens for the unidentified species during the survey were collected for further identification at the Forestry Herbarium, Museum of Natural History, University of the Philippines, Los Baños.

2.2.2. Quantitative Structure Analysis

The relative density, relative dominance, and relative frequency values for each tree species were computed to obtain their Importance Value (IV). Importance values were estimated as the sum of the species' relative density, relative dominance, and relative frequency (Mueller-Dombois & Ellenberg, 1974). Diversity indices such as Shannon, Simpson's and Evenness of the sampling quadrats were also estimated using Multivariate Statistical Package (MVSP 3.2).

2.2.3. Heavy metal accumulation in the leaves

Detection of Nickel accumulation was done in the field. The leaves of the plants were washed with distilled water and then crushed on filter paper impregnated with dimethylglyoxime. The appearance of pink on the filter paper indicates the presence of Nickel. A portable X-Ray Fluorescence (XRF) (SciAps model X200) at the Philippine Nuclear Research Institute (PNRI), Department of Science and Technology (DOST) was used to determine the heavy metal content (in %) of the herbarium specimens of the located plants.

2.2.4. Soil Analysis

Soil samples were collected at 0-30 cm depth from five sampling points on each plot. The bulked samples per site were sent to the College of Agriculture and Food Science, University of the Philippines Los Baños (UPLB) for the determination of pH, organic matter (OM), nitrogen (N), phosphorous (P), potassium (K), calcium, magnesium, soil electrical conductivity (EC), and cation exchange capacity (CEC). Heavy metal content was determined using a portable XRF, SciAps model X200 at the Philippine Nuclear Research Institute (PNRI)-Department of Science and Technology (DOST).

Table 1. Comparison of soil physico-chemical characteristics and heavy metal contents of the ultramafic sites in Sta. Cruz, Mindoro Occidental, Zambales, and Surigao, Philippines and Sabah, Malaysia

Parameters	Mindoro	Zambales	Surigao	Sabah
pH	6.2 ± 0.15	6.5 ± 0.08	6.0 ± 0.26	6.64 ± 0.52
OM (%)	3.81 ± 0.10	2.0 ± 0.66	5.8 ± 4.25	No Data
N (%)	0.23 ± 0.005	No Data	No Data	0.36 ± 0.15
P (mg/kg)	12.19 ± 2.25	No Data	No Data	2.83 ± 1.85
K ($cmol_c$/kg soil)	0.24 ± 0.06	No Data	No Data	0.3 ± 0.2
Ca ($cmol_c$/kg soil)	1.66 ± 0.67	5 ± 0.87	6.8 ± 2.79	9.0 ± 5.5
Mg ($cmol_c$/kg soil)	10.7 ± 1.25	11 ± 1.06	6.3 ± 1.74	13.0 ± 5.6
Ca:Mg	0.14 ± 0.047	0.45	1.07	0.9 ± 0.8
EC (µS/cm)	299 ± 41	91.6 ± 24.78	353 ± 122	No data
CEC ($cmol_c$/kg soil)	30 ± 5	30.5 ± 3	24.7 ± 6.12	30.2 ± 12.8
Mn (ppm)	2,557 ± 885	No Data	No Data	4421 ± 1082
Ni (ppm)	3357 ± 1135	No Data	No Data	2941 ± 1082
Cu (ppm)	60 ± 25	No Data	No Data	No data
Cr (ppm)	5618 ± 2025	No Data	No Data	5826 ± 2202
Fe (ppm) (%)	133,963 ± 38,654	No Data	No Data	No data
Al (%)	0.33 ± 0.04	No data	No data	No data
Si (%)	2.25 ± 0.14	No data	No data	No data
Reference	This study	(Ata et al., 2016)	(Ata et al., 2016)	(Quintela-Sabarís et al., 2019)

Table 2a. Characteristics of study plots in Sta. Cruz, Mindoro Occidental, Philippines

Plot	Plot 1	Plot 2	Plot 3	Plot 4
Size (m^2)	20m × 20m	20m × 20m	20m × 20m	20m × 20m
Poles and saplings	30	102	240	31
Number of small trees (10 cm max DBH)	5	27	16	11
Number of medium size trees (40 cm DBH)	1	0	0	0
Number of Large trees (> 60 cm DBH)	0	0	0	0

Table 2b. Dominant tree species and family and number of native trees across four plots in Sta. Cruz, Mindoro Occidental, Philippines

	Plot 1	Plot 2	Plot 3	Plot 4
Dominant tree species	*Ridsdalea merrillii* (Elmer) J.T.Pereira *Wrightia pubescens* R. Br. subsp. *laniti* (Blanco)Ngan *Alstonia scholaris* (L.) R.Br.	*Barringtonia racemosa* (L.) Blume ex DC. *Acacia auriculiformis* A.Cunn. ex Benth. *Alstonia macrophylla* Wall. ex G.Don	*Cratoxylum formosum* (Jack) Dyer *Buchanania arborescens* (Blume) Blume *Ridsdalea merrillii* (Elmer) J.T.Pereira	*Buchanania arborescens* (Blume) Blume *Vitex parviflora* Juss. *Nymphanthus curranii* Lour.
Dominant family	Apocynaceae Rubiaceae Fabaceae	Apocynaceae Lecythidaceae Anacardiaceae	Apocynaceae Anacardiaceae Fabaceae	Phyllanthaceae Anacardiaceae Lamiaceae
Number of native tree species	8	11	10	16

2.2.5. Identification of Conservation Status

The identification of the conservation status was made only for tree species identified in the four 20m × 20m plots. At the local scale, the DAO-2017-11 was used to determine the conservation status of endemic species, while the IUCN RedList-2021-3 for the global scale.

3. RESULTS

3.1. Soil characteristics

The results of the soil analysis are presented in Table 1. Generally, the soil can be characterized as acidic, with average pH of 6.2 and low organic matter (3.8%), Nitrogen (0.23%), Phosphorus (12.9 mg kg^{-1}), and Potassium (0.24 $cmol_c$ kg^{-1} soil) contents. The Calcium content is also low (1.66 $cmol_c$ kg^{-1} soil) while the Magnesium content is very high (10.7 $cmol_c$ kg^{-1} soil). The soil EC is 299 µS cm^{-1} and the CEC is 30 $cmol_c$ kg^{-1} soil. The XRF readings showed a high amount of iron (14%), Manganese (2,725 ppm), Chromium (6,372 ppm), and Nickel (3,674 ppm), which are typical of lateritic soil. The soil Aluminum is 0.3% while the Silicon in the soil is 2.25%.

3.2. Floristic composition and conservation status

A total of 43 morpho-species belonging to 36 genera and 25 families were recorded from all the sampled plots (Table 1, 2, 3, 4, and 5). Table 2 shows the characteristic composition of the four study plots in Sta. Cruz, Mindoro Occidental, Philippines. The tree flora existing across the plots is dominated by individuals of poles and saplings (< 10 cm dbh) to small trees (10 cm to < 30 cm dbh) with *Vitex parviflora* and *Buchanania arborescens* as the species with 27 cm dbh and 28 cm dbh, respectively, and only Plot 1 had a medium-sized tree (30 cm to 60 cm dbh, i.e., *Alstonia* sp.) with 40 cm dbh (Table 2). These values are generally higher compared with those found in ultramafic areas in Zambales and Surigao del Norte (Supplementary Table 1). The major species (based on stem density) from plots 1, 3, and 4 are all native species. In Plot 2, however, one non-native species (*Acacia auriculiformis*) coexists with two native species, *Barringtonia racemosa* and *Alstonia macrophylla* (Table 2). A total of 33 tree species with 463 individuals were recorded in the four 20m x 20m established plots (Table 3). Apocynaceae has four species, while Anacardiaceae and Phyllanthaceae each have three species. Following that are the families Fabaceae, Lamiaceae, Myrtaceae, Rubiaceae, and Sapindaceae, each with two identified species. The native species with the highest number of individuals were *Buchanania arborescens* (126), *Cratoxylum formosum* (84), and *Ridsdalea merrillii* (70), which are all pioneer species (Table 3).

Top ten tree species with the highest IV were *B. arborescens* (59.57%), *Cratoxylum formosum* (41.06%), *Acacia auriculiformis* (28.35%), *Ridsdalea merrillii* (25.82%), *Barringtonia racemosa* (16.46%), *Vitex parviflora* (15.06%), *Tabernaemontana pandacaqui* (11.74%), *Wrightia pubescens* (10.36%), *Alstonia macrophylla* (8.63%) and *Alstonia scholaris* (8.36%) (Table 3), of which *Vitex parviflora*) is listed as endangered (EN) based on the DENR Administrative Order (DAO) 2017-11, although it is only a Least Concern (LC) species under the IUCN Red List (Table 3). *Millettia merrillii* and *Carallia brachiata* are listed as Other Threatened Species (OTS) in the DAO 2017-11 (Table 3).

Table 3. List of tree species surveyed in Sta. Cruz, Mindoro, Occidental, Philippines with their tree count, relative density, relative frequency, relative dominance, importance value and conservation status

Species	N	RDEN (%)	RFRE (%)	RDOM (%)	IV (%)	Conservation StatuS
ANACARDIACEAE						
Anacardium occidentale L.	1	0.22	1.69	0.16	2.07	LC (IUCN)
[1]*Buchanania arborescens* (Blume) Blume	126	27.21	6.78	25.57	59.57	LC (IUCN)
Mangifera indica L.	3	0.65	1.69	1.80	4.14	DD (IUCN)
APOCYNACEAE						
[9]*Alstonia macrophylla* Wall. ex G.Don	15	3.24	3.39	2.00	8.63	LC (IUCN)
[10]*Alstonia scholaris* (L.) R.Br.	5	1.08	5.08	2.20	8.36	LC (IUCN)
[7]*Tabernaemontana pandacaqui* Poir.	16	3.46	5.08	3.20	11.74	LC (IUCN)
[8]*Wrightia pubescens* R.Br. subsp. laniti (Blanco) Ngan	11	2.38	5.08	2.90	10.36	LC (IUCN)
BURSERACEAE						
Canarium asperum Benth. in Hook.f.	1	0.22	1.69	0.06	1.97	LC (IUCN)
CALOPHYLLACEAE						
Calophyllum pentapetalum L.	1	0.65	3.39	0.26	4.30	
CANNABACEAE						
Trema orientalis (L.) Blume	2	0.43	1.69	0.14	2.27	LC (IUCN)
EUPHORBIACEAE						
Macaranga tanarius (Linn.) Muell.-Arg	1	0.22	1.69	0.04	1.95	LC (IUCN)
FABACEAE						
[3]*Acacia auriculiformis* A.Cunn. ex Benth.	34	7.34	3.39	17.62	28.35	LC (IUCN)
Millettia merrillii Perkins	4	0.86	3.39	0.64	4.89	OTS (DAO-2017-11)
HELICTERACEAE						
Helicteres hirsuta Lour.	3	0.65	3.39	0.54	4.58	
HYPERICACEAE						
[2]*Cratoxylum formosum* (Jack) Dyer	84	18.14	5.08	17.84	41.06	LC (IUCN)
LAMIACEAE						
Gmelina arborea Roxb. ex Sm.	1	0.22	1.69	0.32	2.23	LC (IUCN)
[6]*Vitex parviflora* Juss.	13	2.81	6.78	5.47	15.06	EN (DAO-2017-11); LC (IUCN)
LAURACEAE						
Litsea glutinosa (Lour.) C.B.Rob.	3	0.65	3.39	0.34	4.38	LC (IUCN)
LECYTHIDACEAE						
[5]*Barringtonia racemosa* (L.) Blume ex DC.	36	7.78	1.69	6.99	16.46	LC (IUCN)
MELIACEAE						
Swietenia macrophylla King	1	0.22	1.69	0.06	1.97	VU (IUCN)
MISCELLANEOUS						
Miscellaneous	2	0.65	3.39	0.44	4.48	
MORACEAE						
Ficus fiskei Elm.	1	0.22	1.69	0.20	2.11	LC (IUCN)
MYRTACEAE						
Eucalyptus sp.	1	0.22	1.69	0.20	2.11	
Syzygium sp.	3	0.65	3.39	0.48	4.52	
PHYLLANTHACEAE						

Species	N	RDEN (%)	RFRE (%)	RDOM (%)	IV (%)	Conservation StatuS
Antidesma ghaesembilla Gaertn	7	1.51	3.39	2.12	7.02	LC (IUCN)
Breynia racemosa	1	0.22	1.69	0.12	2.03	
Nymphanthus curranii Lour.	3	0.65	1.69	0.12	2.46	
RHIZOPHORACEAE						
Carallia brachiata (Lour.) Merr.	3	0.65	1.69	0.68	3.02	OTS (DAO-2017-11)
RUBIACEAE						
Nauclea orientalis (L.) L.	2	0.43	1.69	1.40	3.53	LC (IUCN)
[4]*Ridsdalea merrillii* (Elmer) J.T.Pereira	70	15.12	5.08	5.61	25.82	
SAPINDACEAE						
Dodonaea viscosa (L.) Jacq.	1	0.22	1.69	0.16	2.07	LC (IUCN)
Guioa koelreuteria (Blanco) Merr.	2	0.43	1.69	0.14	2.27	LC (IUCN)
THYMELAEACEAE						
Wikstroemia indica (L.) C.A. Mey	3	0.65	3.39	0.20	4.24	
TOTAL	463	100	100	100	300	

3.3. Understory species and the ground cover

In this rapid assessment, the ten most abundant understory species in order of abundance are: *Tabernaemontana* sp. > *Wrightia pubescens* R.Br. subsp. *laniti* > *Ridsdalea merrillii* > *Tabernaemontana pandacaqui* > *Acacia auriculiformis* > *Helicteris hirsuta* > *Buchanania arborescens* > *Litsea glutinosa* > *Alstonia macrophylla* > *Scolopia luzonensis* (Table 4 and Table 5). Notably, six of the understory species were included in the list of tree species with the highest IV as shown in Table 3.

3.4. Plant Diversity

Overall, the plant diversity of the area in Sta. Cruz, Occidental Mindoro is moderate (H`=2.726) across the four quadrats (Table 6). Plot 4 has the highest H` index (2.27) among the sampled plots. It is dominated by *B. arborescens, Vitex parviflora,* and *Nymphanthus curanii.* Contrarily, Plot 3, which is dominated by *C. formosum*, *B. arborescens,* and *R. merrillii* has the lowest value of Shannon index (i.e., 2.05). Based on Simpson's index, Plot 2 had the highest species richness (0.8605) while Plot 4 had the lowest (0.7964). Simpson's index indicates the richness/rarity of species occurring across plots. Six species that are only present in Plot 4 include *Breynia racemosa, Dodonaea viscosa, Nymphanthus curranii, Syzygium sp., Scolopia luzonensis, sp., and Diospyros ferrea* which are species typically growing on ultramafic sites.

3.5. Aluminum (Al) hyperaccumulation

The XRF screening of the herbarium specimens of the native plants collected from the wooded grassland in Sta. Cruz, Mindoro Occidental showed accumulation of the macronutrients such as Calcium, Nitrogen, Phosphorous, and Potassium as well as iron and manganese which are micronutrients. Twenty-two species of plants accumulated more than 1% Al in their leaves (Table 7).

The plants that accumulated Al also accumulated Silica. The leaf Silica is generally higher in all the species except in *Barringtonia* sp. and *Carallia* sp. where Al is slightly higher than Si. It is only in the leaves of *Psychotria* sp., where the amount of Al equal is equal to the amount of Si.

4. DISCUSSION

The survey revealed a low level of plant diversity in each plot in Sta. Cruz, Mindoro Occidental. This result can be attributed to the "serpentine factors" typical of ultramafic areas (Adamidis et al., 2014). The low organic matter content, low NPK, low Ca: Mg ratio, and metal-rich soil in the study site may have controlled the types of plants that can thrive in the area. Very low soil Ca: Mg ratio (<1) has been identified as one of the major factors determining species composition and stand structure on ultramafic substrates (Adamidis et al., 2014). The soil in the present study has Ca: Mg ratio of less than one and Prasad and Shivay (2020) reported that the very high levels of Mg competes with Ca nutrition in plants. The same authors emphasized the importance of Calcium for normal plant physiological functioning and survival. In western Iran, the survival rate of a serpentine-endemic *Alyssum inflatum* was reduced at Ca: Mg = 0.4 ratio and maximum at Ca: Mg = 2 (Ghasemi et al., 2018). However, the authors further noted that at a higher Ca: Mg ratio (i.e., > 20)

Table 4. Ten most abundant understorey species on the study plots in Sta. Cruz, Mindoro Occidental, Philippines

Species	Common name	Family	Abundance	Frequency
Tabernaemontana sp.	Tabernaemontana	Apocynaceae	19	2
Wrightia pubescens R.Br. subsp. *laniti* (Blanco) Ngan	Lanete	Apocynaceae	14	2
Ridsdalea merrillii (Elmer) J.T.Pereira	bagáoi	Rubiaceae	14	2
Tabernaemontana pandacaqui Poir.	pandakaki	Apocynaceae	10	2
Acacia auriculiformis A.Cunn. ex Benth.	acacia	Fabaceae	10	1
Helicteris hirsuta L.	danglín-asó	Helicteraceae	8	1
Buchanania arborescens (Blume) Blume	*balinghasai*	Anacardiaceae	6	2
Litsea glutinosa (Lour.) C.B.Rob.	sablot	Lauraceae	5	5
Alstonia macrophylla Wall. ex DC.	batino	Apocynaceae	4	1
Scolopia luzonensis Warb.	anínguai	Salicaceae	3	1

Table 5. Relative cover (RC) of all species recorded in 1 x 1 m plots in Mindoro Occidental, Philippines

Species	Common name	Family name	Sum of % cover	Relative cover
Chromolaena odorata (L.) R.M. King & H.Rob.	gonoi	Asteraceae	0.20	20.00
Themeda sp.		Poaceae	0.07	7.06
Buchanania arborescens (Blume) Blume	balinghasai	Anacardiaceae	0.24	23.53
Alstonia macrophylla Wall. ex DC.	batino	Apocynaceae	0.15	15.29
Acacia auriculiformis A.Cunn. ex Benth.	Acacia	Fabaceae	0.06	5.88
Tabernaemontana pandacaqui Poir.	pandakaki	Apocynaceae	0.04	3.53
Wikstroemia indica (L.) C.A.Mey.	salago	Thymelaeaceae	0.04	3.53
Annonaceae	-	Annonaceae	0.02	2.35
Calophyllum pentapetalum (Blanco) Merr.	pamítoyen	Calophyllaceae	0.02	2.35
Diospyros ferrea (Willd.) Bakh.	batulinau	Ebenaceae	0.02	2.35
Guioa koelreuteria (Blanco) Merr.	aláhan	Sapindaceae	0.02	2.35
Vitex parviflora Juss.	molave	Lamiaceae	0.02	2.35
Ridsdalea merrillii (Elmer) J.T.Pereira	bagáoi	Rubiaceae	0.02	2.35
Scolopia luzonensis Warb.	anínguai	Salicaceae	0.02	2.35
Tabernaemontana sp.	Tabernaemontana	Apocynaceae	0.02	2.35
Breynia racemosa	Breynia	Phyllanthaceae	0.01	1.18
Wrightia pubescens R.Br. subsp. *laniti* (Blanco) Ngan	lanete	Apocynaceae	0.01	1.18

the serpentine endemic species has reduced tolerance for environmental stresses. In this study, the observed high concentrations of heavy metals (e.g. Ni, Cu, and Fe) in soil may have also added additional serpentine syndrome or stress to the plants in the area. Plants exposed to heavy metals generally experience oxidative stress and cellular damage (Wahsha et al., 2012). Serpentine syndrome in plant communities has long been considered as one of the consequences of elevated amounts of metals and nutrient deficiency (Bini & Maleci, 2014).

Compared to the studies conducted in Surigao and Zambales, the tree density, basal area, average DBH of the trees and the Shannon Diversity Index are higher in Mindoro site. These could be attributed to the natural colonization that took place in the partially wooded grassland in Mindoro Occidental. The study sites of Ata et al. (2016) in Surigao and Zambales are mined areas disturbed by mining activities, planted with exotic species, and protected from fire. Several papers proved that natural colonization is faster if there are no exotic species planted in the area (Quintela-Sabarís et al., 2019). On the other hand, the site for this study is part of the wooded grassland reported by De Alban (2009) which has been idle up to the time when the survey for this study was conducted. De Alban (2009) recommended afforestation or reforestation of the extensive grassland in Mindoro Occidental to develop carbon sinks and generate additional fund sources for communities from carbon payments, and more importantly to restore forests and conserve biodiversity.

Table 6. Diversity indices of each quadrat with details on number of species and no. of individuals recorded in the study plots in Sta. Cruz, Mindoro Occidental, Philippines

Plot no.	No. of species	No. of individuals	Simpson (1-D)	Shannon (H)	Evenness (e^H/S)
1	14	59	0.8486	2.226	0.6614
2	16	193	0.86055	2.233	0.5832
3	24	309	0.8152	2.055	0.3254
4	21	109	0.7964	2.271	0.4614
Overall	43	670	0.8937	2.726	0.3551

Table 7. Selected chemical contents (%) of leaves of native woody metallophytes in the wooded ultramafic grassland in Sta Cruz, Mindoro Occidental, Philippines

Scientific Name	Family	Ni*	Al	Si	Fe	Mn	Ca	Mg	P	K
Atalantia sp.	Rutaceae	BDL	0.247	0.549	0.079	0.039	6.04	0.668	0.069	0.487
Barringtonia racemosa	Lecythidaceae	0.002	0.276	0.247	0.057	0.049	1.42	1.982	0.139	2.059
Buchanania arborescens	Anacardiaceae	0.002	0.109	6.2	0.021	0.032	4.21	0.749	0.096	1.009
Calophyllum	Calophyllaceae	0.002	0.121	0.178	0.092	0.028	2.92	0.452	0.022	0.274
Carallia brachiata	Rhizophoraceae	0.001	0.196	0.191	0.042	0.037	3.97	1.806	0.078	0.542
Dodonaea viscosa	Sapindaceae	BDL	0.169	0.232	0.071	0.033	3.53	0.835	0.051	
Evolvulus sp.	Covulvulaceae	BDL	0.1	0.2	0.067	0.029	3.31	0.412	0.030	0.212
Guioa koelreuteria	Sapindaceae	0.001	0.152	1.93	0.030	0.043	2.22	0.646	0.062	0.846
Helicteres hirsuta	Helicteraceae	0.004	0.168	0.258	0.101	0.045	3.15	2.002	0.058	0.566
Millettia merrillii	Fabaceae	BDL	0.231	16.72	0.107	0.059	4.98	0.572	0.094	0.727
Nymphanthus curanii	Phyllanthaceae	0.002	0.09	3.06	0.058	0.030	2.68	0.711	0.042	0.448
Polygala sp.	Polygalaceae	0.005	0.176	0.637	0.246	0.034	1.77	1.393	0.048	0.653
Psychotria sp.	Rubiaceae	BDL	0.161	0.162	0.073	0.034	3.45	0.811	0.051	0.05
Ridsdalea merrillii	Rubiaceae	BDL	0.172	0.187	0.040	0.031	2.19	1.122	0.027	0.468
Sedge-1	Poaceae	0.01	0.17	7.62	0.400	0.049	0.44	BDL	0.070	0.759
Sedge-2	Poaceae	0.006	0.126	10.32	0.206	0.029	0.48	BDL	0.027	0.778
Syzygium sp	Myrtaceae	BDL	0.173	0.199	0.026	0.027	1.12	0.451	0.071	0.446
Tabernamontana pandacaqui	Apocynaceae	0.001	0.185	0.27	0.066	0.048	3.07	0.843	0.122	1.440
Tabernamontana sp.	Apocynaceae	0.003	0.198	0.331	0.098	0.041	2.60	2.316	0.227	1.193
Vitex parviflora	Lamiaceae	0.001	0.143	1.04	0.071	0.027	2.15	1.216	0.262	0.882
Wrightia pubescens	Apocynaceae	0.006	0.149	0.254	0.097	0.069	3.24	1.541	0.392	1.304
Zizyphus sp.	Rhamnaceae	BDL	0.134	0.272	0.070	0.059	2.77	0.863	0.091	1.02

Remark: *BDL – below detection level

One way of restoring the forest and conserving the biodiversity on this ultramafic soil is planting of the species that are native in the area. This study identified 36 of the 43 identified species that are native tree species, which are mostly poles and saplings to small trees. Fruiting trees of the endemic nitrogen-fixing species, *Millettia merrillii*, were found growing in the surveyed areas in Mindoro Occidental. The planting of perennial native nitrogen-fixers had been recommended to help stabilize the serpentine soil, improve site microclimate, and facilitate succession processes. The results of the abundance and IV showed the top three most important species in the study site are *B. arborescens, C. formosum,* and *R. merrillii*, which are all native species. There are also wildlings and saplings of 14 native species that are abundantly growing as undergrowth species and are well established in the area. This suggests that the remnants of the native ones were able to at least survive the serpentine environment in the study site. The map of the ophiolite belt from Yumul Jr et al. (2009) that was overlaid with the map of Mindoro Occidental showed the nearest ultramafic forest to be ca 4 km from plot 3. The presence of populations of native plants from this forested stand may have contributed to the natural regeneration of the area, however, further research is needed to confirm this. Other factors may have also influenced their high dominance, including activation of the soil seed bank and their seed/fruit and regenerative traits. For example, the observed highest tree density, dominance, and frequency of *B. arborescens* among the native species can be attributed to its adaptation to serpentine condition. *B. arborescens* had been reported to be also growing on ultramafic substrates in Sabah, Malaysia and Sulawesi, Indonesia (Proctor, 2003). The species has a berry/fleshy fruit type, which is usually dispersed by faunal vectors (e.g., birds) in two ways, namely, ingesting (endozoochory) and transporting (epizoochory).

The result of the present study also suggests that there is a need to conserve and protect the native remnants against any forms of disturbance to ensure their survival and establishment in the area. Twenty species of the located native plants have reported medicinal values (see e.g., Quisumbing (1951); Al-Snafi (2017); Carag and Buot Jr (2017); Pham et al. (2021); Amelia et al. (2021); Nafeeza et al. (2022)) meriting their conservation. Seed collection of these species should be done. Moreover, *B. arborescens,* C. *formosum*, and *R. merrillii* trees can serve as nurse crops that can help enhance the condition for the germination and growth of other native species. Conservation of their mature individuals or populations as a seed source for reintroduction in the study area should also be conducted. Regular collection of their mature fruits and seeds can be done for the mass production of plants that are native in Mindoro Occidental, for reforestation of areas with the same soil and microenvironment characteristics.

The XRF readings revealed soil characteristic that is typical of lateritic soil, i.e., a high amount of Iron, Manganese, Chromium, and Nickel. Results also revealed that the identified native species have a mechanism to accumulate macronutrients such as Ca, N, P, and K which are generally deficient in the soil and to accumulate high amount of Fe and Mn without toxicity. This implies that the identified native species have plant traits that can tolerate lateritic conditions. Thus, there is a likelihood that the identified native species will also thrive in other ultramafic areas, with such soil conditions. The XRF analysis of the herbarium specimens also revealed that the identified native plants did not accumulate heavy metals such as Cobalt, Copper, Chromium, and Nickel in their leaves and thus, these plants can be classified as excluders of these metals. These metal excluders have the potential for phytostabilization. Similarly, the native metallophytes may also be used for reforestation of the ultramafic grassland in the study area and other similar degraded ultramafic areas. This approach can be less costly and can result in a forest stand comprised of locally adapted species and genotypes resulting in greater floral and faunal diversity (Frouz & Kuráž, 2013). However, more botanical surveys are needed to locate the other native serpentine species in the area that are already well-adapted to the existing edaphic and climatic factors.

In this study, there were no Nickel hyperaccumulating species identified considering the observed high amount of Nickel in the soil samples in all sites. One reason could be the lack of seeds of Nickel hyperaccumulators from the adjacent forest ecosystems. Another reason could be the lack of direct seed dispersal agents which is common in grassland dominated ecosystems. Seed dispersal could also explain the restricted growth of most of the native species in the sites. It is worthy to note that except for *Buchanania arborescens, Ridsdalea merrillii, Tabernaemontana pandacaqui, Vitex parviflora*, and *Wrightia pubescens* subsp. laniti, which are present in the four plots, a number of the native metallophytes were only present in 1-2 plots. At least 16 of the native species have fruits that are reportedly dispersed by birds. These species needing direct dispersal agents can be considered as high-priority candidates for assisted migration or assisted colonization as suggested by Spasojevic et al. (2014) and other references in their article because they are less likely to germinate on the adjacent grassland unassisted. There are native species that were only located in plot 4 that have winged seeds (*Dodonaea viscosa*), have seeds that are less than 2 mm (*Breynia racemosa*, *Nymphanthus curanii*, *Wikstroemia* sp.), and unisexual (*Diospyros ferrea*). These species also need to be grown and mass-produced in the nursery for future reintroduction in the grassland for restoration.

Aluminum accumulators are plants that can accumulate at least 1% or 1000 mg kg^{-1} in their leaves or shoots (Malta et al., 2016). Potential Aluminum hyperaccumulators from 18 families that are growing on the wooded grassland in this study were documented. Aluminum hyperaccumulation had been reported for several woody species (Watanabe, 2022). It is interesting to note that the amount of Silica accumulated by the leaves of the native species that are Al-hyperaccumulator in this study are rarely less than or equal but in general higher compared to the concentration of the accumulated Aluminum. Malta et al. (2016) suggested that Si also acts as a ligand of Al which explains the higher Si accumulation in Al hyperaccumulating plants. This information supports the ability of these identified native plants to grow in acid soils and can be used in phytoremediation of Al -contaminated soils.

Lastly, there were no wildings of *G. arborea* and *S. macrophylla* in the understorey and only a few wildlings of *A. auriculiformis* were observed despite planting them during the previous reforestation programs in the site. *Anacardium occidentale* was also grown in the two sites but there were also no wildlings in the study sites. This observation indicates that wildings of the three exotic species may not thrive in the sites in Mindoro. In serpentine grasslands, natives generally out-compete exotics (Harrison et al., 2020). Moreover, spontaneous growth of the native species will be better if there are no exotic species (Quintela-Sabarís et al., 2019) provided there are adjacent populations of native plants (Řehounková et al., 2021).

5. CONCLUSION

The rapid assessment showed that the plant diversity in Sta. Cruz, Mindoro Occidental was generally low to moderate. Although low in diversity, important native species, which are mostly at poles and saplings stage, were found to be growing on the serpentine grassland. The soil condition in the surveyed area exhibit characteristics typical of a serpentine/ lateritic environment. Thus, the present study revealed that the surveyed area in Sta. Cruz, Mindoro Occidental is home to ecologically important serpentine species/metallophytes that need to be immediately conserved. However, regular vegetation monitoring is highly recommended for a better understanding of the plant diversity in the area. Overall, the findings presented herein serve as technical information that is important for the creation and implementation of conservation programs in the area and coming up with a list of the native species in Sta Cruz, Mindoro Occidental. It is also interesting to note that a number of the located species are also growing in other countries. A collaborative study within the regions can be done regarding the uses of these native plants on phytostabilization and reforestation of serpentine grassland.

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Declaration of Competing Interest

The authors declare that no competing financial or personal interests that may appear and influence the work reported in this paper.

References

Adamidis, G. C., Kazakou, E., Baker, A. J. M., Reeves, R. D., & Dimitrakopoulos, P. G. (2014). The effect of harsh abiotic conditions on the diversity of serpentine plant communities on Lesbos, an eastern Mediterranean island. *Plant Ecology & Diversity*, *7*(3), 433-444. https://doi.org/10.1080/17550874.2013.802050

Al-Snafi, A. E. (2017). A review on *Dodonaea viscosa*: A potential medicinal plant. *IOSR Journal of Pharmacy*, *07*, 10-21. http://www.iosrphr.org/papers/v7i2V1/B0702011021.pdf

Amelia, P., Nugroho, A. E., Hirasawa, Y., Kaneda, T., Tougan, T., Horii, T., & Morita, H. (2021). Two new bisindole alkaloids from *Tabernaemontana macrocarpa* Jack. *Journal of Natural Medicines*, *75*(3), 633-642. https://doi.org/10.1007/s11418-021-01510-4

Ata, J. P., Luna, A. C., Tinio, C. E., Quimado, M. O., Maldia, L. S., Abasolo, W. P., & Fernando, E. S. (2016). Rapid assessment of plant diversity in ultramafic soil environments in Zambales and Surigao del Norte, Philippines. *Asian Journal of Biodiversity*, *7*(1). https://asianscientificjournals.com/new/publication/index.php/ajob/article/view/864

Baker, A. J. M., & Whiting, S. N. (2008, 14-17 October). *Metallophytes — A Unique Biodiversity and Biotechnological Resource in the Care of the Minerals Industry* Mine Closure 2008: Proceedings of the Third International Seminar on Mine Closure, Johannesburg. https://papers.acg.uwa.edu.au/p/852_2_Baker/

Bini, C., & Maleci, L. (2014). THE "SERPENTINE SYNDROME" (H. JENNY, 1980): A PROXY FOR SOIL REMEDIATION. *EQA - International Journal of Environmental Quality*, *15*(15), 1-13. https://doi.org/10.6092/issn.2281-4485/4547

Carag, H., & Buot Jr, I. E. (2017). A checklist of the orders and families of medicinal plants in the Philippines. *Sylvatrop, The Technical Journal of Philippine Ecosystems and Natural Resources*, *27*(1&2), 49-49. https://www.ukdr.uplb.edu.ph/journal-articles/5175/

Cardace, D., & Meyer-Dombard, D. A. R. (2014). Bedrocke and geochemical controls on extremophile habitats. In N. Rajakaruna, R. S. Boyd, & T. B. H. (E (Eds.), *Plant Ecology and Evolution in Harsh Environments*. Nova Science Publishers. https://novapublishers.com/shop/plant-ecology-and-evolution-in-harsh-environments/

Chathuranga, P. K. D., Dharmasena, S. K. A. T., Rajakaruna, N., & Iqbal, M. C. M. (2015). Growth and nickel uptake by serpentine and non-serpentine populations of Fimbristylis ovata (Cyperaceae) from Sri Lanka. *Australian Journal of Botany*, *63*(2), 128-133. https://doi.org/10.1071/BT14232

De Alban, J. D. T. (2009). *Report on the Physical Component of the Conservation Needs Assessment of Mindoro Island*. M. C. Mindoro Biodiversity Conservation Foundation, Philippines.

Echevarria, G. (2018). Genesis and Behaviour of Ultramafic Soils and Consequences for Nickel Biogeochemistry. In A. Van der Ent, G. Echevarria, A. J. M. Baker, & J. L. Morel (Eds.), *Agromining: Farming for Metals: Extracting Unconventional Resources Using Plants* (pp. 135-156). Springer International Publishing. https://doi.org/10.1007/978-3-319-61899-9_8

Erskine, P., van der Ent, A., & Fletcher, A. (2012). Sustaining Metal-Loving Plants in Mining Regions. *Science*, *337*(6099), 1172-1173. https://doi.org/doi:10.1126/science.337.6099.1172-b

Fernando, E. S., Celadiña, D. N., Tandang, D., Lillo, E. P., & Quimado, M. O. (2020). Brackenridgea (Ochnaceae) in the Philippines, with notes on foliar nickel hyperaccumulation in the genus. *Gardens' Bulletin Singapore*, *72*(2), 255–273. https://doi.org/10.26492/gbs72(2).2020-09

Fernando, E. S., Quimado, M. O., & Doronila, A. I. (2014). *Rinorea niccolifera* (Violaceae), a new, nickel-hyperaccumulating species from Luzon Island, Philippines. *PhytoKeys*(37), 1-13. https://doi.org/10.3897/phytokeys.37.7136

Fernando, E. S., Quimado, M. O., Trinidad, L. C., & Doronila, A. I. (2013). The potential use of indigenous nickel hyperaccumulators for small-scale mining in The Philippines. *2013*, *1*(1), 6. https://doi.org/10.15243/jdmlm.2013.011.021

Frouz, J., & Kuráž, V. (2013). Soil Fauna and Soil Physical Properties. In J. Frouz (Ed.), *Soil Biota and Ecosystem Development in Post Mining Sites*. CRC Press. https://doi.org/10.1201/b15502

Galey, M. L., van der Ent, A., Iqbal, M. C. M., & Rajakaruna, N. (2017). Ultramafic geoecology of South and Southeast Asia. *Botanical Studies*, *58*(1), 18. https://doi.org/10.1186/s40529-017-0167-9

Garnica-Díaz, C., Berazaín Iturralde, R., Cabrera, B., Calderón-Morales, E., Felipe, F. L., García, R., M. Hulshof, C. (2022). Global Plant Ecology of Tropical Ultramafic Ecosystems. *The Botanical Review*. https://doi.org/10.1007/s12229-022-09278-2

Ghasemi, R., Share, H., Sharifi, R., Boyd, R. S., & Rajakaruna, N. (2018). Inducing Ni sensitivity in the Ni hyperaccumulator plant *Alyssum inflatum* Nyárády (Brassicaceae) by transforming with CAX1, a vacuolar membrane calcium transporter. *Ecological Research*, *33*(4), 737-747. https://doi.org/10.1007/s11284-018-1560-x

Gonzalez, J. C. T., Dans, A. T. L., & Afuang, L. E. (2000). *Rapid Island-Wide Survey of Terrestrial Fauna and Flora on Mindoro Island, Philippines*. Mindoro Biodiversity Conservation Foundation, Muntinlupa City, Philippines. https://www.mbcfi.org.ph/wp-content/uploads/2022/03/8_Mindoro_Island_Wide_Survey.pdf

Harrison, S., Spasojevic, M. J., & Li, D. (2020). Climate and plant community diversity in space and time. *Proceedings of the National Academy of Sciences*, *117*(9), 4464-4470. https://doi.org/10.1073/pnas.1921724117

Lillo, E. P., Fernando, E. S., & Lillo, M. J. R. (2019). Plant diversity and structure of forest habitat types on Dinagat Island, Philippines. *Journal of Asia-Pacific Biodiversity*,*12*(1),83-105. https://doi.org/10.1016/j.japb.2018.07.003

Malta, P. G., Arcanjo-Silva, S., Ribeiro, C., Campos, N. V., & Azevedo, A. A. (2016). *Rudgea viburnoides* (Rubiaceae) overcomes the low soil fertility of the Brazilian Cerrado and hyperaccumulates aluminum in cell walls and chloroplasts. *Plant and Soil*, *408*(1), 369-384. https://doi.org/10.1007/s11104-016-2926-x

Mueller-Dombois, D., & Ellenberg, H. (1974). *Aims and Methods of Vegetation Ecology*. John Wiley & Sons, New York.

Nafeeza, S., Pushpakumari, B., & Reddy, V. J. S. (2022). Phyto-pharmacological potential of *Buchanania arborescens* (Anacardiaceae), on wound healing and CNS depressent activities in albino wistar rats. *World Journal of Pharmaceutical and Life Sciences*, *8*(2), 94-102. https://www.wjpls.org/home/article_abstract/2503

Perez, A. d. C., Faustino-Eslava, D. V., Yumul, G. P., Dimalanta, C. B., Tamayo, R. A., Yang, T. F., & Zhou, M.-F. (2013). Enriched and depleted characters of the Amnay Ophiolite upper crustal section and the regionally heterogeneous nature of the South China Sea mantle. *Journal of Asian Earth Sciences*, *65*, 107-117. https://doi.org/10.1016/j.jseaes.2012.09.023

Pham, H. N. T., Vuong, Q. V., Bowyer, M. C., & Scarlett, C. J. (2021). Phytochemical Profiles and Potential Health Benefits of *Helicteres hirsuta* Lour. *Proceedings*, *70*(1), 43. https://doi.org/10.3390/foods_2020-07804

Prasad, R., & Shivay, Y. S. (2020). Calcium as a plant nutrient. *International Journal of Bio-resource and Stress Management*, *11*(5), i-iii. https://doi.org/10.23910/1.2020.2075a

Proctor, J. (2003). Vegetation and soil and plant chemistry on ultramafic rocks in the tropical Far East. *Perspectives in Plant Ecology, Evolution and Systematics*, *6*(1), 105-124. https://doi.org/10.1078/1433-8319-00045

Proctor, J., Argent, G., & Madulid, D. (1998). Forests of the ultramafic mount Giting-Giting, Sibuyan Island, the Philippines. *Edinburgh Journal of Botany*, *55*(2), 295-316. https://doi.org/10.1017/S0960428600002201

Quimado, M. O., Fernando, E. S., Trinidad, L. C., & Doronila, A. (2015). Nickel-hyperaccumulating species of *Phyllanthus* (Phyllanthaceae) from the Philippines. *Australian Journal of Botany*, *63*(2), 103-110. https://doi.org/10.1071/BT14284

Quintela-Sabarís, C., Masfaraud, J.-F., Séré, G., Sumail, S., van der Ent, A., Repin, R., Leguédois, S. (2019). Effects of reclamation effort on the recovery of ecosystem functions of a tropical degraded serpentinite dump site. *Journal of Geochemical Exploration*, *200*, 139-151. https://doi.org/10.1016/j.gexplo.2019.02.004

Quisumbing, E. (1951). *Medicinal Plants of the Philippines*. Manila (Philippines), Bureau of Printing.

Řehounková, K., Jongepierová, I., Šebelíková, L., Vítovcová, K., & Prach, K. (2021). Topsoil removal in degraded open sandy grasslands: can we restore threatened vegetation fast? *Restoration Ecology*, *29*(S1), e13188. https://doi.org/10.1111/rec.13188

Sarmiento, R. T. (2018). Vegetation of the ultramafic soils of Hinatuan Island, Tagana-An, Surigao Del Norte: An assessment as basis for ecological restoration. *Ambient Science*, *5*(2), 44-50. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3804618

Spasojevic, M. J., Damschen, E. I., & Harrison, S. (2014). Patterns of seed dispersal syndromes on serpentine soils: examining the roles of habitat patchiness, soil infertility and correlated functional traits. *Plant Ecology & Diversity*, *7*(3), 401-410. https://doi.org/10.1080/17550874.2012.678506

Tupaz, C. A. J., Watanabe, Y., Sanematsu, K., Echigo, T., Arcilla, C., & Ferrer, C. (2020). Ni-Co Mineralization in the Intex Laterite Deposit, Mindoro, Philippines. *Minerals*, *10*(7), 579. https://doi.org/10.3390/min10070579

van der Ent, A., Echevarria, G., Pollard, A. J., & Erskine, P. D. (2019). X-Ray Fluorescence Ionomics of Herbarium Collections. *Scientific Reports*, *9*(1), 4746. https://doi.org/10.1038/s41598-019-40050-6

Wahsha, M., Bini, C., Fontana, S., Wahsha, A., & Zilioli, D. (2012). Toxicity assessment of contaminated soils from a mining area in Northeast Italy by using lipid peroxidation assay. *Journal of Geochemical Exploration*,*113*, 112-117. https://doi.org/10.1016/j.gexplo.2011.09.008

Watanabe, T. (2022). Basic understanding of aluminum accumulator plants. *Eurasian Journal of Forest Research*, *22*, 59-62. https://doi.org/10.14943/EJFR.22.59

Yumul Jr, G. P., Jumawan, F. T., & Dimalanta, C. B. (2009). Geology, Geochemistry and Chromite Mineralization Potential of the Amnay Ophiolitic Complex, Mindoro, Philippines. *Resource Geology*, *59*(3), 263-281. https://doi.org/10.1111/j.1751-3928.2009.00095.x

Supplementary Table 1. Comparative average of tree (>1 cm dbh) density, basal area, DBH and diversity indices of the 20 x 20 m plots in Mindoro, Zambales, and Surigao del Norte

	Mindoro	**Zambales**	**Surigao**
Tree (>1 cm dbh) density	28.5	5.45	5.25
Basal area	0.4	0.22	0.21
Average DBH	5.25	3.36	2.62
No of species	43	23	55
No of individuals	670	106	287
Evenness_e^H/S	0.3551	0.8797	0.9167
Shannon-Weiner Index (H)	2.726	0.6500	1.1071
Simpson's Index (D)	0.1063	0.1976	0.0775
Simpson's Index (1-D)	0.8937	0.8024	0.9225
Reference	This study	(Ata et al., 2016)	(Ata et al., 2016)