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# Species composition and diversity of flora in an abandoned mine in an island province in the Philippines: Implications for rehabilitation strategies

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**Abstract.** Understanding the floristic composition of degraded lands, such as abandoned mine areas, is crucial for guiding effective rehabilitation. This study assessed an abandoned copper mine in an island province of the Philippines, which remained unrehabilitated after operations ceased, to document its floral species composition and diversity. Ten quadrats were established to identify thriving plant species and evaluate their conservation status and diversity indices. A total of 42 species from 27 families were recorded, with Fabaceae and Pteridaceae most represented. Twenty-one species were native to the Philippines. Dominant species included Oldenlandia corymbosa, Pteris sp., Fimbristylis littoralis, Acacia auriculiformis, Stachytarpheta jamaicensis, and Nephrolepis cordifolia. Based on plant categories, vegetation was mainly composed of ferns (40%) and shrubs or small trees (38%). Diversity indices showed heterogeneous patterns among quadrats, with some exhibiting ecological balance, while others were dominated by only a few species—typical of metal-contaminated environments. Quadrat 4 (Q4) was the most balanced and diverse, suggesting that despite harsh site conditions, patches of vegetation continue to thrive. Future studies should investigate soil properties of Q4 to guide site-specific rehabilitation strategies.

## 1 Page layout

Undeniably, mining plays a significant role in the economic growth of countries worldwide, particularly those classified as low- and middle-income nations. In the Philippines, the country ranks among the top five most mineralized nations globally, with abundant mineral reserves—especially aluminum, copper, gold, iron, and nickel [1].

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However, mining also brings significant environmental challenges, often leaving permanent scars on the landscape when not properly rehabilitated. These impacts include the contamination of environmental media, displacement of communities, landscape alteration, biodiversity loss, and vegetation degradation. Between 2001 and 2020, nearly 1.4 million hectares of global forestlands were lost due to mining and related activities [2]. Although there are currently no active mining operations in the island province of Marinduque, Philippines, the area has a history of mining-related disasters, with some environmental impacts still evident today. One of the most notable cases is the abandoned copper mine in the municipality of Mogpog, which operated from 1968 to 1980. This activity left behind a large open pit—now referred to as a mine-made lake—as well as disturbed vegetation that remains apparent to this day. A recent study by Nolos et al. [3] investigating potentially toxic elements (PTEs) in soil and dust from the abandoned site revealed elevated concentrations of cadmium, chromium, copper, lead, and nickel—all of which are toxic and some classified as carcinogenic. These contaminants pose serious health risks and are subject to dispersal through natural processes such as weathering, which may further exacerbate their spread in the surrounding environment. Alarmingly, communities and schools are located near the abandoned mine, heightening the risk of exposure to these harmful elements. To reduce the potential health risks and limit the spread of contaminants, rehabilitating the vegetative cover in the area is essential. Given this need for rehabilitation, understanding the current floristic composition of the area is crucial. Rehabilitation refers to the process of restoring a disturbed site to a condition close to its original state—although not necessarily returning it to its exact former condition—in order to prevent further environmental degradation. Identifying signs of ecological recovery, such as increased floral species diversity and the presence of thriving native species, can significantly aid in the development of effective rehabilitation strategies. In line with this, the study aims to: (a) assess the floral species in the abandoned mine area, (b) determine their conservation and endemicity status, and (c) calculate diversity indices. This study will contribute to the identification of suitable plant species for revegetation and long-term rehabilitation initiatives in the abandoned mine area of Marinduque, Philippines.

## 2 Material and methods

### 2.1 Study area

The study was conducted in the island province of Marinduque in the Philippines (Fig. 1), specifically in the municipality of Mogpog, where an abandoned copper mine is located at 13.50248° N and 121.86409° E. The municipality has a Type III climate based on the Corona Classification System, characterized by no pronounced wet or dry season. The dry season typically spans from November to April, while the rest of the year is generally wet. Based on climatological data retrieved from the NASA Prediction of Worldwide Energy Resources (2015-2024), the area has the following annual median values: temperature (27.65C), relative humidity (82.07%), precipitation (2,416.3 mm), and surface soil wetness (83.5%) [4]. Additionally, the municipality of Mogpog primarily consists of loam to clay loam soils, with the area around the abandoned mine classified as

Balanacan clay. Land use in the municipality is predominantly agricultural, covering about 9,000 hectares, followed by forest areas at approximately 251 hectares, and residential areas at around 54 hectares [5].

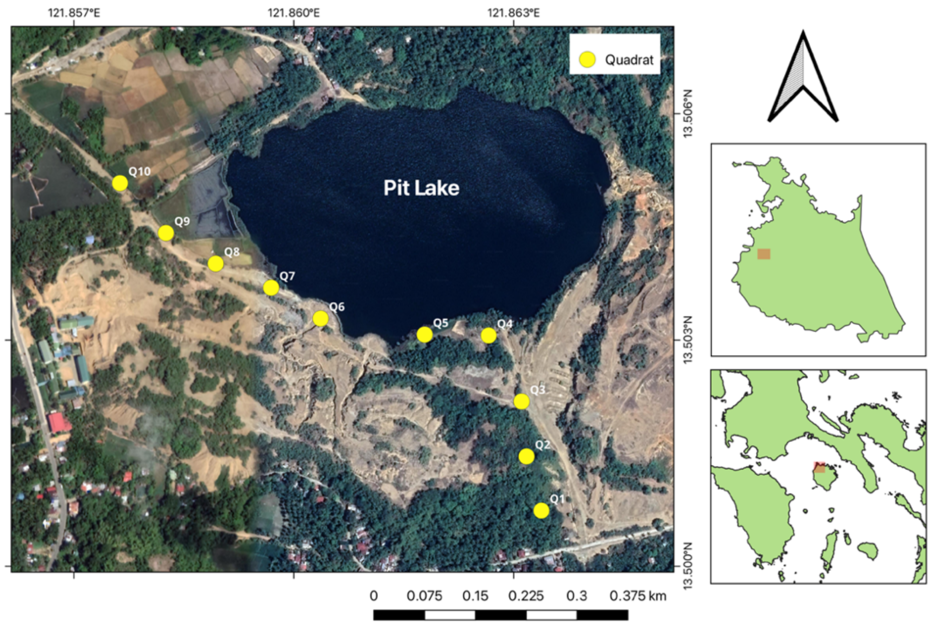


**Fig. 1.** Study area with the locations of the quadrats.

### 2.2 Sampling and species identification

The sampling was conducted in March 2025, which is considered part of the dry season. As shown in Fig. 1, ten quadrats measuring 5 by 5 meters were strategically positioned in the vicinity of the abandoned mine site, considering accessibility, representativeness, and spatial distribution. The coordinates of the established quadrats were recorded using a handheld Global Positioning System (GPS) device. For the identification of floral species, PictureThis, a free plant identification mobile application available on both iOS and Android devices, was used. This app has also been employed in other studies and has been reported to have an accuracy of more than 90% [6,7]. Identification results were further validated using Co's Digital Flora of the Philippines and the study by Medianista and Labay [8], which conducted a floral assessment in the same area. The floral species were also categorized into the following groups: ferns and fern allies, grasses and grass-like plants, shrubs and small trees, trees, vines, and others/mixed. Observations made in the area were also recorded.

### 2.3 Conservation status and endemicity assessment

The conservation status of the recorded floral species was determined using the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, which is accessible online. The species were classified into the following categories: Not Validated, Data Deficient, Least Concern, Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild, and Extinct.

To identify the endemicity of the floral species, Co's Digital Flora of the Philippines was also used. Based on this source, species were categorized as either Native, Naturalized—non-native species that have become established in an area without human intervention—or Cultivated.

### 2.4 Biodiversity indices

The biodiversity indices of floral species in each quadrat were calculated using PAST version 4.03 software. These include Species Richness (Taxa_S), Number of Individuals, Simpson's Dominance Index (Dominance_D), Simpson's Diversity Index (Simpson_1-D), Shannon Diversity Index (Shannon_H), Shannon Evenness Index (Evenness_e^H/S), Margalef's Richness Index (Margalef), and Pielou's Evenness Index (Equitability_J).

### 2.5 Data analysis

Descriptive analysis and visualization were performed using Microsoft Excel version 16.52 and IBM SPSS Statistics version 25, respectively. Map visualizations, on the other hand, were generated using QGIS version 3.30.

## 3 Results and discussion

### 3.1 Taxonomic classification

The floral assessment in the abandoned mine area revealed 27 plant families and 42 floral species, with Fabaceae and Pteridaceae having the highest number of species, at 14 and 10, respectively (Table A.1.). Similarly, in the study conducted by Medianista and Labay [8], Fabaceae was also the most represented family in the area. Fabaceae, commonly known as the legume or bean family, is considered the second most diverse plant family and is widely distributed across the globe. Studies have shown that species in the Fabaceae family, such as Prosopis laevigata, can tolerate nutrient-poor soils and areas heavily laden with potentially toxic elements like cadmium, chromium, lead, and nickel [9]. Meanwhile, Pteridaceae, a family of ferns, comprises around 50 genera and an estimated 950 species. Like the Fabaceae family, it is also widely distributed across the globe, especially in temperate and tropical regions such as the Philippines. Various species under Pteridaceae have also been documented thriving in harsh mining environments, including a copper-gold mining site in the Philippines [10]. The top floral species—each with more than 100 counts—were Oldenlandia corymbosa (n = 384), Pteris sp. (n = 360), Fimbristylis littoralis (n = 210), Acacia auriculiformis (n = 140), Stachytarpheta jamaicensis (n = 106), and Nephrolepis cordifolia (n = 105). As for Pteris sp., a fern species, several studies have confirmed its ability to hyperaccumulate contaminants such as potentially toxic elements (PTEs). At an arsenic-contaminated tailings site in Southwestern China, species of this fern were able to hyperaccumulate high levels of arsenic and thallium, reaching concentrations of up to 11,000 mg/kg [11]. This fern has also been shown to stabilize other PTEs, including copper, cadmium, and lead. The bioaccumulation of PTEs in Pteris sp. has been attributed to soil pH, with slightly acidic soils enhancing the bioavailability of these elements. Another abundant floral species in the abandoned mine site is Fimbristylis littoralis, a native species in the Philippines. Studies on Fimbristylis ferruginea, a species from the same genus, have shown its ability to accumulate both organic contaminants and PTEs. This species has also been shown to accumulate cadmium and chromium in the soil, with accumulation rates reaching up to 90% [12]. Other commonly studied floral species with phytoremediation potential that were also abundant in the study area include Acacia auriculiformis, a naturalized tree in the Philippines, and Nephrolepis cordifolia, a fern native to the Philippines [13]. A. auriculiformis showed that it can tolerate high concentrations of arsenic, copper, iron, and even radioactive environments. This species also forms a symbiotic relationship with rhizobia in the soil, leading to increased nitrogen levels that support the growth of surrounding plants. In addition, its large crown provides a shading effect, promoting the emergence of herbaceous plants and grasses in its understory, thereby aiding the transformation of degraded land into shrubland. However, monitoring of this species is warranted due to its invasive properties. Similarly, the fern N. cordifolia demonstrates phytoremediation capabilities, thriving in areas with inorganic contaminants. It has also been identified as a hyperaccumulator of arsenic and mercury.

### 3.2 Conservation status and endemicity

Aside from the abundant floral species in the study area, it is also important to consider the IUCN Red List status and endemicity of the recorded species, as shown in Table A.1. Seventeen floral species are listed as "Least Concern," meaning they are at very low risk of extinction. One species, Leea philippinensis—a native tree species in the Philippines—is categorized as "Near Threatened". Given its conservation status and native origin, it is worth exploring the phytoremediation potential of this species in the study area, especially since it was previously recorded there by Medianista and Labay [8]. Regarding endemicity, 21 species were recorded as "Native," referring to those that occur naturally in a specific geographic area without human introduction. Eighteen species were classified as "Naturalized," meaning they have overcome environmental and biological barriers and now reproduce regularly without human assistance in a new area. One species, Cymbopogon citratus (commonly known as lemongrass), was identified as "Cultivated" while the remaining two species were listed as "Not Evaluated" [13]. Furthermore, spatial distribution based on endemicity shows that the majority of native species are concentrated in Quadrats 3 and 4 which had 8 and 7 native species, respectively. In Quadrat 3, these species include Fagraea fragrans, Ficus septica, Leea philippinensis, Nephrolepis cordifolia, Onychium japonicum, Pericampylus glaucus, Rauvolfia sp., and Tabernaemontana pandacaqui. Meanwhile, the native species recorded in Quadrat 4 were Calamus sp., Dimocarpus longan, Ficus septica, Leea philippinensis, Nephrolepis cordifolia, Rauvolfia sp, and Tabernaemontana pandacaqui. The environmental conditions in these areas, particularly soil physico-chemical properties, may warrant further investigation. These properties include pH, PTE concentrations, and nutrient content, which have been identified as key predictors of floral species diversity.

### 3.3 Floral categories

It was also recorded that most of the floral categories identified in the abandoned mine area were ferns and shrubs/small trees, with 855 and 812 individuals, respectively (Fig. 2). Ferns are generally considered plants with adaptive mechanisms that allow them to survive in harsh conditions, such as mined-out areas. This indicates their potential role in the initial stages of rehabilitating degraded landscapes. Ferns also possess metal exclusion abilities—this means they can prevent the excessive uptake of PTEs like arsenic and copper into their biomass while still absorbing essential micronutrients. Other adaptive mechanisms that enable ferns to thrive and become widely distributed in harsh environments include: efficient spore-based reproduction due to their lightweight and easily dispersed spores; tough fronds that reduce water loss; well-developed rhizomes for water storage; and their symbiotic relationships with fungi (mycorrhizae), which enhance nutrient uptake. With these adaptive strategies, ferns are regarded as pioneer species in ecological succession, contributing to the transformation of degraded environments into more favorable conditions. Following ferns, shrubs and small trees were the next most abundant plant groups. These are generally regarded as transitional species that begin to thrive once environmental conditions in degraded lands improve.

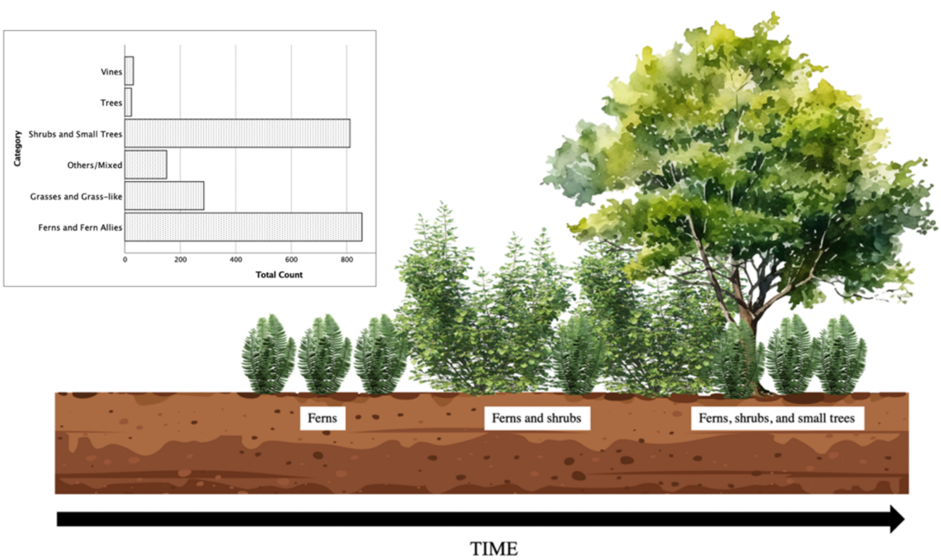


**Fig 2.** Floral succession patterns and corresponding plant category distribution observed in the study area.

The reclaimed mining areas that natural ecological succession occurs over time, with increasing biodiversity marked by the gradual establishment of more plant species—particularly ferns and shrubs or small trees [14]. Similar observation was recorded in the study area (Fig. 2).

### 3.4 Floral categories

The diversity indices of floral species recorded in the abandoned mine area were calculated and are presented in Table 1. Among the quadrats assessed, Quadrat 4 (Q4) exhibited the highest species richness (Taxa_S) with 13 floral species, while Quadrat 6 (Q6) recorded only 2 species, namely Acacia auriculiformis and Fimbristylis littoralis. As shown in Fig. 2, vegetation in Q6 is sparse to nearly absent, which visually supports its low diversity. The average species richness across the study area was 7 floral species, indicating relatively low diversity, which is typical of stressed environments such as mined-out areas. In a similar study conducted in Zambia, researchers examined the species richness of trees in seven mine wastelands and found that the site with the highest metal concentration recorded the lowest species richness [15]. The number of individual plants per quadrat ranged from 21 to 475, with an average of 216 individuals across the ten quadrats. Regarding dominance (Dominance_D), Q3 exhibited the highest dominance value (0.71), primarily attributed to a dominant fern species, which, as previously discussed, possesses adaptive mechanisms suited for harsh environments. Under Simpson's Diversity Index (Simpson_1-D), several quadrats demonstrated relatively high diversity values—Q4 (0.85), Q9 (0.82), and Q10 (0.75)—suggesting more favorable ecological conditions that could serve as focal points for further monitoring and rehabilitation efforts. Considering the full range of diversity indices, Q4 emerges as the most balanced and diverse quadrat. It has the highest species richness (Taxa_S = 13), highest Simpson's Index (0.85), highest Shannon Index (H = 2.17), highest Margalef index (2.33), and highest equitability (J = 0.85). The plant community in Q4 includes ferns, shrubs, trees, and other floral categories, indicating that the site is likely in the mid to late stages of secondary succession.

**Table 1.** Diversity indices for each quadrat (Q).

| Index | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Ave |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Taxa_S | 3 | 15 | 9 | 13 | 6 | 2 | 4 | 4 | 9 | 9 | 7 |
| Individuals | 80 | 475 | 430 | 173 | 137 | 350 | 21 | 134 | 66 | 292 | 216 |
| Dominance_D | 0.33 | 0.66 | 0.71 | 0.15 | 0.61 | 0.52 | 0.26 | 0.44 | 0.18 | 0.25 | 0.41 |
| Simpson_1-D | 0.67 | 0.34 | 0.29 | 0.85 | 0.39 | 0.48 | 0.74 | 0.56 | 0.82 | 0.75 | 0.59 |
| Shannon_H | 1.10 | 0.90 | 0.67 | 2.17 | 0.84 | 0.67 | 1.36 | 0.99 | 1.92 | 1.56 | 1.22 |
| Evenness_e^H/S | 1.00 | 0.16 | 0.22 | 0.67 | 0.39 | 0.98 | 0.98 | 0.67 | 0.76 | 0.53 | 0.64 |
| Margalef | 0.46 | 2.27 | 1.32 | 2.33 | 1.02 | 0.17 | 0.99 | 0.61 | 1.91 | 1.41 | 1.25 |
| Equitability_J | 1.00 | 0.33 | 0.30 | 0.85 | 0.47 | 0.97 | 0.98 | 0.72 | 0.88 | 0.71 | 0.72 |

## 4 Conclusion

The abandoned mine area in the island province of Marinduque, Philippines, was primarily composed of floral species belonging to the Fabaceae and Pteridaceae families. Notably, species with more than 100 individual counts in the area included Oldenlandia corymbosa, Pteris sp., Fimbristylis littoralis, Acacia auriculiformis, Stachytarpheta jamaicensis, and Nephrolepis cordifolia. Regarding conservation status, the recorded floral species varied as follows: 17 species were classified as Least Concern, 1 as Near Threatened, and 23 as Not Evaluated or Not Yet Determined. In terms of endemicity, 21 species were identified as native, 8 as naturalized, and 2 had not been evaluated. The native species—mostly composed of ferns and shrubs or small trees—present potential for phytoremediation research, as they are already established and thriving in the area. Ferns, in particular, are recognized for their important role in the initial stages of ecological rehabilitation in degraded landscapes such as mined-out areas. These are typically followed by shrubs and small trees, which act as transitional species during ecological succession. Additionally, the results of the biodiversity indices revealed heterogeneous recovery across the assessed quadrats. Some quadrats exhibited early signs of ecological balance, while others remained dominated by a few species—a pattern that is typical of metal-contaminated environments. Notably, Quadrat 4 (Q4) emerged as the most diverse based on the diversity indices and may serve as a reference site for future phytoremediation efforts in the area.

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