Explorations on the knowledge and biodiversity of Philippine lichen fungi have progressed recently. However, comparatively little attention has been given to the species composition along a lowland secondary forest ecosystem. Thus, the study aimed to provide information on the occurrence of lichen species in relation to various land use types of Mt. Musuan of Mindanao Island, surrounded by forest fragments and cultivated agricultural areas. A series of transect walks and opportunistic sampling revealed a total of 38 lichen species distributed in 26 genera and 14 families. Among the land use types, the mixed species forest harbors the highest recorded species with 22, followed by teak forest and built-up (peak/summit) with 15 and 14 species, respectively. Lichens with the most represented families were revealed to be Graphidaceae with 10 species; Caliciaceae with six species; Physciaceae, Parmeliaceae, and Arthoniaceae with three species each; and Pyrenulaceae, Collemataceae, Letrouitiaceae, and Trypetheliaceae with two species each. Out of these collections, two species – *Letrouitia subvulpina* (Nyl.) Hafellner and *Pyrenula globifera* (Eschw.) Aptroot – were new records in the Philippines. The results of this study will provide information to encourage effective management and biodiversity conservation efforts of various land use types, as lichens are sensitive to anthropogenic threats and pressures from environmental conditions.

Keywords: Mindanao, new record, non-vascular, secondary forest, species richness

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INTRODUCTION

The Philippines is a biodiversity hotspot home to 1262 lichen species (Paguirigan et al. 2020) and a repository of diversely unique natural biota with a high level of endemism and many threatened and endangered species (Amoroso et al. 2012). Explorations on the knowledge and biodiversity of Philippine lichen fungi have progressed recently [e.g. Fajardo and Bawingan (2019); Lucban and Paguirigan (2019); Paguirigan et al. (2019); Bawingan et al. (2019, 2022)]. However, critical threats due to habitat loss are faster than ever, pushing poorly understood species to the brink of extinction before they are even discovered.

Within greater Mindanao, for instance, explorations have been conducted – highlighting the descriptions and biodiversity patterns of lichens in a mountain ecosystem with multiple vegetation types and elevational gradients (Azuelo and Puno 2018; Cababan et al. 2020; Magday et al. 2020). Nonetheless, the aforementioned observations may not be readily applicable to a secondary forest ecosystem situated in lowland areas, where abiotic factors such as limited humidity and light gradient may not result in significant stratification of species distribution (Benzing 1990; Graham and Andrade 2004) and reduced forest cover attributed to dwindling diversities of tree species available as a substrate (Murphy and Lugo 1986).

Lichens inhabit all terrestrial habitats of the Earth, yet they are among the most underexplored groups of living organisms. The majority of the biodiversity and conservation efforts put greater emphasis on “charismatic species,” leaving a challenge to develop effective conservation and protection strategies for these less-known and studied groups (Nascimbene et al. 2013; Gheza et al. 2020).

Lichens play an important ecological role in their native habitats and are sensitive to changes in moisture and air pollution; hence, monitoring the populations can help scientists track the effects of climate change and air quality on ecosystems (Bates 2002; Nimis et al. 2002). In addition, they also provide a wide range of microhabitats for insects – including shelter, camouflage as survival strategies, and insulation (Haines and Renwick 2009; Fang et al. 2020). Moreover, it has been known to provide ethnobotanical and pharmacological roles in traditional medicine systems around the world (Agelet and Vallès 2003; Azuelo et al. 2011; Chandra et al. 2017; Yang et al. 2021). Thus, well-deserved attention is important not just for maintaining biodiversity and ecosystem function but for conservation for both cultural and medical reasons as well.

Among the mountain ecosystems in the central region of Mindanao Island is Mt. Musuan, which is surrounded by remains of forest and cultivated agricultural areas near Valencia City and is considerably rich in fauna and flora assemblages (Amoroso et al. 2002). However, increased human-induced interventions in the nearby areas and climate change pose threats to the already dwindling flora, fauna, and fungi. With the help of afforestation initiatives nearly 20 years ago, various trees have emerged, which – through time – have created a favorable microclimatic condition, paving the opportunity for other tree species to thrive (Aribal et al. 2015) and, consequently, bark-dwelling lichens.

To date, comparatively little attention has been given to the species composition of lichen fungi along a lowland secondary forest ecosystem in the Philippines; hence, this study was undertaken.

MATERIALS AND METHODS

Study Site

The study was conducted in Mount Musuan at Maramag in the province of Bukidnon in Central Mindanao. This site is an isolated, low grass-covered andesitic lava dome and tuff cone that rises to 646 meters above sea level (masl) and has an area of 425 ha, with 169 of those being both natural and plantation forests (Paquit et al. 2023). Its climatic data recorded with air temperature ranges from 25–27 °C with an average of 26 °C plus a relative humidity of 70–85% (80%). The soil temperature (5-cm depth) is 25–26 °C (–28°C) with an annual rainfall of 150–250 mm (190 mm on average) (Azuelo et al. 2020).

Prior to the conduct of the study, a field reconnaissance survey was carried out to verify the presence of lichen species in different land use types. The different land use types were identified based on the Mt. Musuan resource map (Figure 1) developed by Paquit et al. (2023). These land use types were: [a] LTER plot (350 masl); [b] Thailand acacia plantation (TAP; 405-450 masl); [c] mixed species forest (MSF; 455–500 masl); [d] grass-shrubland (505–550 masl); [e] teak forest (TF; 530–545 masl); [f] Pinus caribaea plantation (PP; 555–600 masl); and [g] built-up peak/summit (BUP; 605+ masl). A GPS (global positioning system) was used to generate spatial information such as the altitude and coordinates of each identified land use type.

Collection of Lichen Samples

An inventory of lichen species was conducted from March–April 2023 across identified land use types of Mt. Musuan (Figure 2) using a series of transect walks. In each land use type, an opportunistic sampling method was employed to record all the lichen species. Specific
microhabitats limited to fallen logs, trunks of trees and shrubs (at 200 cm from the ground level), and soils were searched. Only corticolous and terricolous lichens were assessed.

Collected specimens were placed in individual bags and properly labeled with detailed information for further examination in the laboratory. Voucher specimens were dried and deposited in Central Mindanao University Herbarium (CMUH) in Bukidnon, Philippines.

**Lichen Identification**

Morpho-anatomical characters were examined using a stereoscope and an optical microscope together with available dichotomous taxonomic keys from various scientific articles and journals. The following studies were the most routinely used: Wolseley and Aguirre-Hudson (1995; for macrolichens), Lücking et al. (2009), Rivas Plata et al. (2011; for Graphis and Graphidaceae), Schumm and Aptroot (2012; for general tropical lichens.

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Figure 1. Map of Mt. Musuan, Bukidnon, southern Philippines: [A] map of Mindanao Island; [B] Mt. Musuan resource map adopted from Paquit et al. (2023).

Figure 2. Different identified land use types of Mt. Musuan, Bukidnon, southern Philippines: [a] LTER plot; [b] teak forest; [c] Thailand acacia plantation; [d] mixed species forest; [e] grass-shrubland; [f] *Pinus caribaea* plantation; [g] built-up peak/summit.
from Southeast Asia), and Aptroot (2021; Pyrenulaceae and Trypetheliaceae). We also consulted Paguirigan et al. (2020) to confirm citations and records in the most current checklist of Philippine lichens. Subsequently, identified specimens were referred to experts for verification.

Data Analysis
Descriptive statistics such as graphs and seriation analysis to visualize the distribution of lichen fungi across land use types were generated using PAST (Palaeontological Statistics Software).

RESULTS

Species Composition across Land Use Types
An initial field inventory of the lichen diversity in Mt. Musuan identified a total of 38 species distributed in 26 genera and 14 families. Notably, two lichen species were revealed as new records for the Philippines, viz. Letrouitia subvulpina and Pyrenula globifera (Figure 3). The majority (63%) of the collected specimens were microlichens, characterized morphologically with crustose thalli formations, whereas only 37% were macrolichens. Further results portrayed Graphidaceae as the most represented family with 10 species – followed by Caliciaceae (6 spp.), Physciaceae (3 spp.), Parmeliaceae (3 spp.), and Arthoniaceae (3 spp.) (Table 1).

New Records in the Philippines

**Letrouitia subvulpina** (Nyl.) Hafellner
**Specimen examined.** PHILIPPINES: Mt. Musuan, Maramag, Bukidnon, Philippines, 443 masl, 7°52’48” N 125°03’53” E, on the bark of *Koompassia excelsa*, 14 Mar 2023; ECT50 (CMUH).

Habitat and geographical distribution. Bark of tropical forests; Cambodia and Nepal (Shi et al. 2015), Sri Lanka, Indonesia, Africa, Caribbean Islands, South America, Australia, Pacific Islands (Hafellner 1983), and new to the Philippines.

**Pyrenula globifera** (Taylor) Hale

**Specimen examined.** PHILIPPINES: Mt. Musuan, Maramag, Bukidnon, Philippines, 443 masl, 7°52’48” N 125°03’53” E, on the bark of *Koompassia excelsa*, 14 Mar 2023; ECT50 (CMUH).

Habitat and geographical distribution. Bark of tropical forests; Cambodia and Nepal (Shi et al. 2015), Sri Lanka, Indonesia, Africa, Caribbean Islands, South America, Australia, Pacific Islands (Hafellner 1983), and new to the Philippines.

Table 1. List of lichen species found in Mt. Musuan.

<table>
<thead>
<tr>
<th>Macrolichens Class, Order</th>
<th>Family</th>
<th>Scientific name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecanoromycetes</td>
<td>Parmeliaceae</td>
<td>Parmelinopsis minarum (Vain.) Elix &amp; Hale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parmotrema cristiferum (Taylor) Hale</td>
</tr>
<tr>
<td></td>
<td></td>
<td>P. tinctorum (Despr. ex Nyl.) Hale</td>
</tr>
<tr>
<td>Lecanoromycetes</td>
<td>Caliciaceae</td>
<td>Dirinaria applanata (Fée) D.D. Awasthi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. picta (Sw.) Clem. &amp; Shear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pyxine petricola Nyl.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pyxine sp.</td>
</tr>
<tr>
<td></td>
<td>Physciaceae</td>
<td>Heterodermia obscurata (Nyl.) Trevis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H. propagulifera (Vain.) J.P. Dey</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H. speciosa (Wulfen) Trevis.</td>
</tr>
<tr>
<td>Lecanoromycetes</td>
<td>Pannariaceae</td>
<td>Physma byrsaeum (Afxel. ex Ach.) Tuck.</td>
</tr>
<tr>
<td>Peltigerales</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coccocarpiaceae</td>
<td>Coccocarpia epiphylla (Fée) Kremp.</td>
</tr>
<tr>
<td></td>
<td>Collemataceae</td>
<td>Leptogium cyanescens (Ach.) Körb.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L. moluccanum (Pers.) Vain.</td>
</tr>
<tr>
<td>Microlichens Class, Order</td>
<td>Family</td>
<td>Scientific name</td>
</tr>
<tr>
<td>Dothideomycetes</td>
<td>Trypetheliaceae</td>
<td>Astrothelium sp.</td>
</tr>
<tr>
<td>Trypetheliales</td>
<td></td>
<td>Bogoriella decipiens (Müll. Arg.) Aptroot &amp; Lücking</td>
</tr>
</tbody>
</table>
Remarks. The ascospores information is similar to *L. vulpina*, *L. muralis*, and *L. sayeri*, with stair-type ascospores, sometimes muriform with 2–4 spores per ascus (Dombrowski 2022).

*Pyrenula globifera* (Eschw.) Aptroot

Specimen examined. PHILIPPINES: Mt. Musuan, Maramag, Bukidnon, Philippines, 473 masl, 7º52’49” N 125º03’60” E, on the bark of *Glochidion album*, 14 Mar 2023; ECT72 (CMUH).

Habitat and geographical distribution. Pantropical (Aptroot 2021); new to the Philippines.

Remarks. This pantropical species produces ascci containing two muriform ascospores (Aptroot and Cáceres 2013); moreover, it has an inspersed hamathecium and UV-thallus due to the absence of lichexanthone (Aptroot 2021).

Distribution of Lichen Species across Land Use Types

Among the land use types of Mt. Musuan, MSF harbors most of the lichen individuals (Figure 4). As a result, a high proportion of species were recorded in MSF, which comprises 22 out of 38 lichen species – followed by TF, BUP, and LTER plot with 15, 14, and 11 species, respectively. The remaining land use types which host fewer species were grass-shrubland (10), PP (8), and TAP (6) (Figure 4A).

Seriation analysis highlights the occurrence of lichen species across land use types (Figure 4C). Among the lichen species, *Cryptothecia* spp. of Arthoniaceae were widely distributed, which spans across land use types. In addition, nine lichen species were broadly distributed, found to be observed at more than three land use types. Meanwhile, 17 lichen species documented in this study exhibited restricted distribution, which was found to be present only in one land use type, *viz. Letrouitia subvulpina* and *Phaeographis* sp. recorded exclusively in TF, *Astrothelium* sp. in LTER plot, *Bacidia* sp., and *Septotrapelia triseptata* in grass-shrubland. Among the land use types, MSF houses the most numbered rare lichens with nine species, followed by BUP with three rare species.

DISCUSSION

Findings in the current study suggest that lichen species richness in Mt. Musuan is closely related to the availability of various tree species combined with canopy openness. This observation was depicted in MSF, which houses the richest species composition. Although characterized as one
of the plantation forests, several tree species have emerged successfully in the area. These include *Rhus tritenensis*, *Breyna vitis-idea*, *Koompassia excelsa*, *Neonauclea media*, and *Wikstroemia lanceolata* with a mean stem density of 5333/ha and a mean diameter at breast height (DBH ± SE) of 8.14 ± 0.35 cm (Paquit *et al.* 2023). Such trees possessed variable traits, including bark type and texture, which provided vast substrate options to host corticolous (bark-dwelling) foliose and crustose lichen species in the area. No fruticose species was found in the surveyed sites. In addition to the availability of various tree species, MSF also possessed open canopy densities, allowing the lichens to receive a greater proportion of the sunlight available for food production.

Figure 4. Lichen species across land use types: [A] species richness; [B] number of individuals; [C] kinds of species across land use types. Note: [TF] teak forest; [TAP] Thailand acacia plantation; [MSF] mixed species forest; [GS] grass-shrubland; [PP] *Pinus caribaea* plantation; [BUP] built-up peak/summit
Conversely, the occurrence of lichen species decreased in the LTER plot. This land use type was part of the natural forest patch of Mt. Musuan with dense canopy cover and relatively dominated by understory vegetation – specifically, *Calamus* sp. This confirms the positive influence of various tree species and canopy openness on lichens, similar to the findings of Benítez et al. (2019), who reported that the richness of lichen species composition highly depends on tree species richness and canopy openness. The observed relationship was consistent with other land use types. For instance, lichen species composition decreased gradually in abundance with land use types dominated by single tree species such as in TAP and PP. Similarly, the TF dominated by plantations of *Tectona grandis* and BUP with *Gmelina arborea* also revealed a decline in lichen species composition. However, the forest stand in TAP and PP displays high canopy cover and branch density, which could be one of the reasons why these areas hosted the fewest lichen species. This microenvironmental condition is considered suboptimal for the growth of many lichen species because it traps more humidity, which encourages greater competition for bryophytes (Bäcklund et al. 2016).

Among the land use types, grass-shrubland was the only area dominated primarily by *Imperata cylindrica*. This dry land type served as the preferred microhabitat for *Septotrapelia triseptata* and *Bacidia* sp., colonizing the exposed slope of the area and growing directly over the soil (terricolous lichens). A study by Sipman et al. (2013) also observed growths of such species on the slope of Mt. Mantalingahan, Palawan, within 300 masl. In high-altitude grassland, terricolous lichens have been considered as indicators of human-induced disturbances (Rai et al. 2011). Considering the abundance of *Septotrapelia triseptata* and *Bacidia* sp. in the area, these can be potential indicator species of dry tropical grassland since they can only be found thriving and colonizing such areas.

A total of 38 lichen species were distinguished in Mt. Musuan, which is few compared to other tropical forest ecosystems worldwide. More than half of the recorded species are restricted to a single land use type. The observed restricted distribution could be attributed to variations in the available potential substrates across different land use types. As noted, lichens thrive in specific ecological conditions and microsites provided by host trees (Cordero-S et al. 2021; Enquist et al. 2019; Bartels and Chen 2012), which supports the disparity in abundance and distribution.

The majority of the lichen species identified in Mt. Musuan are crustose, *i.e.* crust-like and tightly attached to their substrate. These types of lichens are generally overlooked in similar studies (Barajas-Morales and Jimenez 1990); nevertheless, they have been considered the most diverse and abundant growth form, contributing significant biomass in a tropical dry forest (Miranda-González and McCune 2020).

Due to their unique poikilohydric nature, lichens are susceptible to periodic desiccation, making these organisms sensitive to both natural and anthropogenic disturbances (Chuquimarca et al. 2019). The history of habitat conversion has intensified Mt. Musuan’s dry climatic conditions, resulting in low species richness of foliose lichens. In response to such conditions, foliose lichens evolved to acquire thalli with a narrow surface area such as those in Caliciaceae and Physciaceae, which minimizes the evaporative loss. More importantly, Mt. Musuan was surrounded by cultivated areas and open degraded sites, which may explain the absence of fruticose lichens – the most sensitive group of lichens (Fenton 1960; Blum 1973). Several studies conducted in habitats with extreme environmental pressures have also confirmed that crustose and foliose growth forms were the most adaptive (Zulkify et al. 2011; Bawingan 2014). Indeed, simpler thallus morphology forces lichens to minimize demands for nutrient accumulation, limit water loss (Armstrong 2017; McCune 2000), and ultimately be able to withstand varying environmental constraints. Among the frequently observed crustose lichens were *Cryptothecia* spp. The commonness of these species across land use types was primarily due to the fact that Mt. Musuan was already a pronounced disturbed habitat. This observation was consistent with the findings of Thüs et al. (2021), who reported that the significant presence of these species and other sterile crustose taxa serves as an indicator of a disturbed forest plot.

Nonetheless, two species were considered as new records in the Philippines, *viz.* *Letrouritia subulpina* and *Pyrenula globifera*. This underscores the importance of comparative attention to secondary forest ecosystems as their habitat types have the potential for discovering more taxa to be added to the Philippine lichen checklist. More importantly, this would encourage effective management and biodiversity conservation efforts of various land use types, as lichens are sensitive to anthropogenic threats and pressures from environmental conditions.

**ACKNOWLEDGMENTS**

The authors would like to express their heartfelt gratitude to the following: Dr. André Aptroot for the verification of several crustose lichen species; Central Mindanao University and the Center for Biodiversity Research and Extension in Mindanao for their unwavering support; the Commission on Higher Education for funding the research project titled “Biodiversity Conservation and Utilization..."
of Products for Long-term Ecological Research Sites”; and Surigao del Norte State University Mainit Campus for granting permission to access their microscopy materials. ECT would like to thank DOST Project STRAND for the scholarship grant. In addition, MDF would like to acknowledge funding from the National Science Foundation (NSF-DEB 1754697 and 1754667).

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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