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Research Article

Pteridophyte Richness and Community Structure in the Tropical Lowland Habitats of Andanan Protected Landscape, Northeastern Mindanao, Philippines

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ABSTRACT

Pteridophytes are among the most diverse vascular plants in the Philippines, with significant conservation and economic value. This study documents the richness and community structure of pteridophytes in the tropical lowland habitats of the Andanan Protected Landscape (APL), North-eastern Mindanao, Philippines. A combination of quadrat sampling and transect walks was used for pteridophyte assessments. A total of 69 species were recorded, belonging to 19 families and 34 genera, representing about 6.3 % of the Philippine pteridophytes. Of these, 11.6 % are threatened, and 2.9 % are Philippine endemics. The Polypodiaceae was the most species-rich family, comprising 17 % of the total species. Forty-eight species were terrestrial, 12 were epiphytes, and six were lithophytes. *Selaginella engleri* Hieron. was the most important species in the area, with the highest importance value (12.77). The APL exhibited high pteridophyte diversity, with Shannon (H'=3.65) and Simpson (D=0.96) indices, and significant variation in species richness among sampling sites ($p<0.05$). Among the sampling sites, Mt. Ararat demonstrated the highest pteridophyte diversity (H'=3.4) and richness (n=56). Multivariate analysis revealed a high degree of community similarity (ANOSIM R=0.31, $p<0.01$), with overlapping compositions between Berseba and Calaitan, while Mt. Ararat showed a more distinct assemblage. The high pteridophyte diversity and the presence of conservation-priority species support the designation of APL as a critical forest landscape for preserving biological communities and their habitats. This study provides a preliminary checklist and distribution of pteridophyte flora to inform management and conservation efforts in the APL, North-eastern Mindanao, Philippines.

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INTRODUCTION

Pteridophytes are vascular plants that lack of wood and do not produce flowers or seeds (Sessa & Der 2016). Traditionally, due to their similar life cycles as spore-producing plants, they were thought to consist of ferns and fern allies (Christenhusz & Chase 2014; Essig 2015; Rivera et al. 2018; Palmer 2018). However, pteridophytes have been reclassified monilophytes (ferns) and lycophytes as recent molecular evidence has revealed that these plants are paraphyletic (Amoroso 2013, 2016; PPG I 2016). Ferns and lycophytes have three main parts such as: stem, fronds, and spores. Ferns are readily identifiable by their true leaves, or fronds (megaphylls), which are typically pinnate and feature branching veins. Their sporangia are densely grouped into structures called sori which are typically found on the leaf's abaxial surface (Babenko et al. 2019). Lycophytes, which possess microphylls, possess diminutive, scale-like structures characterised by a single mid-vein. Their sporangia are individually located on the adaxial side of the unbranched, veined leaves and typically form cone-like structures known as strobili, which are dense clusters of sporophylls (sporangium-bearing leaves) (Mountier 2018). These pteridophytes are found in tropical and temperate climates (Khine et al. 2019), but the low-humidity mountain regions have the highest species diversity (Conda & Bout 2016; Schuettpelz et al. 2016; Cudal et al. 2021).

In the Philippines, approximately 1,100 pteridophytes belonging to 154 genera and 34 families (delos Angeles & Buot 2015; Amoroso et al. 2016; Barcelona 2020). Approximately 274 of these pteridophytes are endemic to the Philippine (Pelser et al. 2011). Mindanao Island comprises 57 % of the country's pteridophytes (Amoroso et al. 2019), with more than 10 % possessing economic significance (Barcelona et al. 2013). Pteridophytes are esteemed for their aesthetic attributes (Aya-Ay 2016), ornamental applications (Amoroso 2013, 2015a), nutritional value and dietary fibres (Amoroso et al. 2017), medicinal properties (Chawa et al. 2015; Coritico & Amoroso 2020), importance as keystone species in forest regeneration (Forbes et al. 2016; Thomas & Cleal 2021), influence on diversity distributions owing to their adaptability to various ecological niches and effective spore dispersal mechanisms (Aros-Mualin et al. 2021), essential role in community composition as pioneer species, their capacity to create microhabitats, and their contributions to soil stabilise (Della & Falkenberg 2019; Merino et al. 2023); and their utility in biodiversity assessment, monitoring, and conservation efforts (Bergeron & Pellerin 2014; Silva et al. 2018; Alcala et al. 2019; Claveria et al. 2019).

Floristic studies in watersheds, riparian areas, ultramafic landscapes, and different forest types in Caraga Region, Northeastern Mindanao, revealed higher vascular plant diversity and occurrence of several threatened species (Aribal & Bout 2009; Demetillo et al. 2016; Lillo et al. 2019; Along et al. 2020; Goloran et al. 2022; Sarmiento et al. 2022; Lleno et al. 2023). The region has the most threatened vascular plant species on Mindanao Island, including pteridophytes such as Mindanao maidenhair fern (*Adiantum mindanaense* Copel.), Flat whisk fern (*Psilotum complanatum* Sw.), and Filmy fern (*Trichomanes zamboanganum* (Copel.) Mor) (Aribal & Bout 2009). Some studies have focused on pteridophytes, including the century-old exploration in some localities of Agusan Province (Copeland 1913) and the recently discovered species of grass fern, *Schizae erecta* Amoroso & Coritico, in Dinagat islands, Surigao Province (Amoroso et al. 2023). These studies emphasised the ecological importance of the region's terrestrial ecosystems as habitats for vascular plants, including pteridophytes. Despite the reported vascular plant diversity, relatively few studies have focused on the richness, diversity, and community structure of pteridophytes, notably in the Caraga region's protected areas.

Pteridophytes are commonly observed in the mountainous areas of Andanan Protected Landscapes, one of the two protected areas in the Agusan del Sur. Despite their abundance in these areas, there is a significant dearth of published works and documented information about these enigmatic species, leaving much of their potential untapped. Security concerns also render it one of the most under-researched protected areas in the Caraga region, with certain locations being inaccessible for surveys (Solania et al. 2021). As local farmers have found the area ideal for agricultural expansion, illegal logging and slash-and-burn farming, or kaingin, threaten the APL. In this study, a preliminary checklist, conservation status, and community structure analysis of pteridophytes are presented to support effective management practices and conservation efforts of protected area managers in the Andanan Protected Landscape, Northeastern Mindanao, Philippines.

MATERIALS AND METHODS

Study Area and Entry Protocol

Pteridophyte sampling were carried out in the forested areas of Andanan Protected Landscape (APL), Bayugan City, Agusan del Sur, Northern Mindanao. Agusan del Sur is the largest province in the Caraga Region, which features marshlands, agricultural landscapes, and substantial forests (Abello-Camarin 2017). Bayugan is the only component city in the province of Agusan del Sur, located at 8° 71' 44" N, 125° 74' 81" E (Figure 1). Bayugan City is also enclosed by land and has two major rivers: the Andanan and Wawa. The city has a Type II climate and lies below the typhoon belt along Mindanao's eastern coast, where tropical depressions and typhoons often hit Surigao del Norte and Visayas. Moreover, it had 74 % of the province's forestland and 26 % of its Alienable and Disposable (A&D) land (PENRO 2018). Timberlands comprise government-owned, national, protected, and reserved forests, whereas A&D areas are public domain lands that deemed inappropriate for forest use (Philippine Presidential Decree No.705 1975). Furthermore, the APL was established by Philippine Proclamation No. 734, s. 1991 (Official Gazette n.d.).

APL is characterised by a patchwork of forest fragments, which include both cultivated and second-growth forests tucked in the southern end of the Diwata Mountains. It provides social, aesthetic, and economic value, encompassing wood, medicinal plants, forest-derived goods, farmland irrigation, and potable drinking water to the local community (Solania et al. 2021). Initially, the APL covered 15,097 hectares but increased to approximately 22,519 hectares to improve watershed and wildlife protection (UNEP-WCMC 2022).

Three sampling sites were selected within APL: Berseba, Mt. Ararat, and Calaitan. The selection of sampling sites was based on accessibility, security, and pteridophyte abundance. These sites were part of the total land area covered by APL, geographically relatively close, and generally considered as a lowland evergreen forest categorised into secondary forest, dipterocarp forests, and agroforest types.

The three sites had varied elevation, slope, temperature, relative humidity, soil type, forest type, and human-induced threats. Calaitan is located at 176.7 ± 7.7 m, with a 13.9 ± 1.9° slope, 32.2 ± 0.7 °C temperature, and 71.2 ± 1.9 % relative humidity. Soil types include loam, sandy, and clayish. Sampling plots near the Calaitan Riverbank are 30–50 metres away. Accessibility made the site vulnerable to logging and resource extraction. In contrast, Mt. Ararat's dense canopy creates humid, well-drained soil. The temperature is 29.5 ± 0.3°C, with 81.5 ± 1.1 % relative humidity. Rough rocks and inaccessibility plagued the terrain. The area has slopes ranging from 15° to 37°, with an elevation of 503.9 ± 18.2 m. Berseba has a topography of 41.6 ± 2.2° and an elevation of 578.3 ± 31.5 m. Access is difficult due to the steep slope. Many gullies, exposed subsoil, and withered rocks were soil erosion shreds. A nearby stream may fill with water during the rainy season. The temperature is 29.4

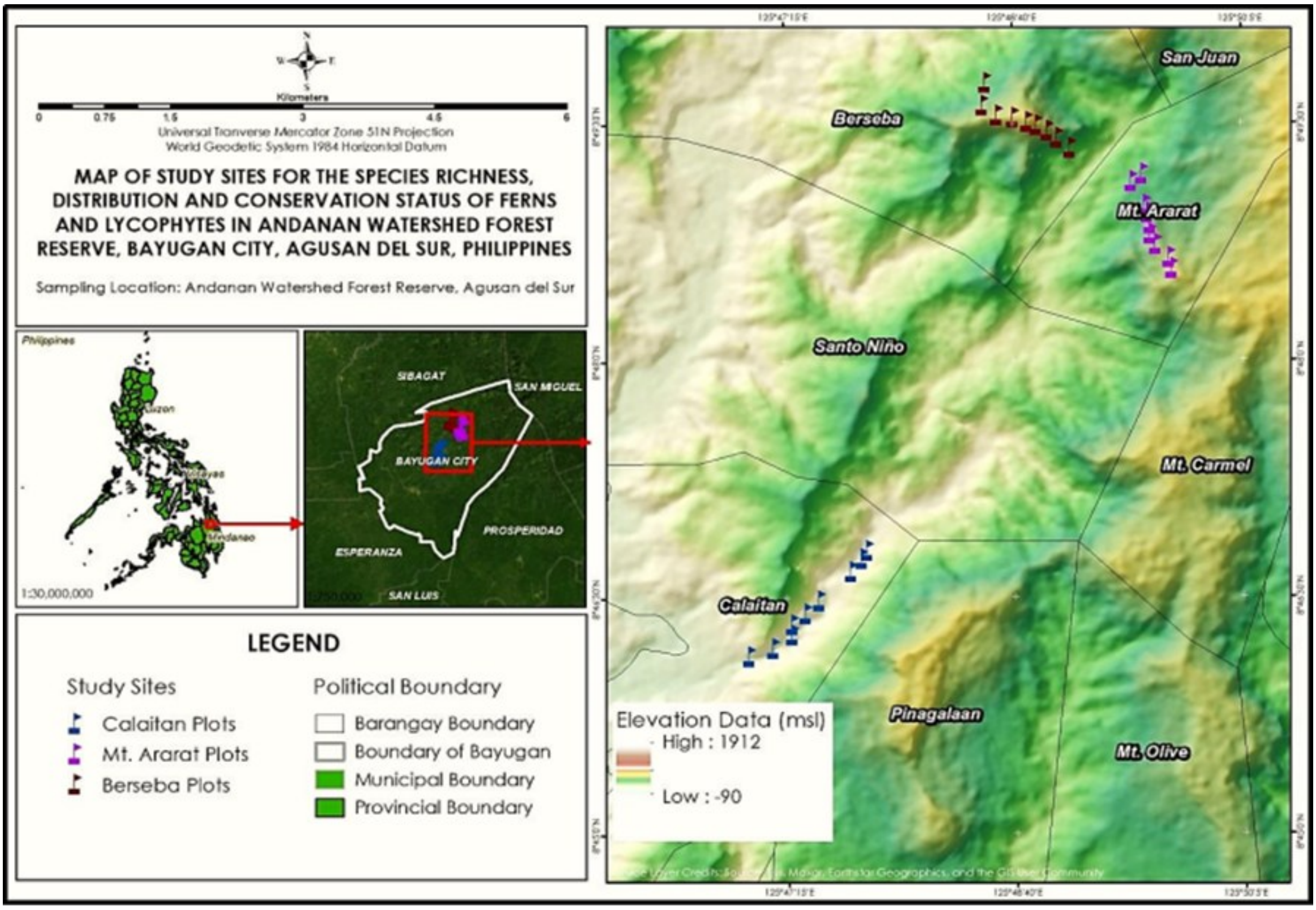

Figure 1. Topographic map of study sites and sampling plots in Andanan Protected Landscape (APL), Caraga Region, Philippines.

°C to 33.2 °C, with a relative humidity of 78.1 ± 2.6 %. Loam and clayish soils are present. Illicit logging, agricultural expansion, slash-and-burning or kaingin, and wildlife poaching threaten biodiversity in the three areas.

The sampling was conducted with resolution No. 2021-11 from the Protected Area Management Board (PAMB) of APL, approved Prior Informed Consent (PIC) from the Local Government Unit (LGU) of Bayugan City, and Wildlife Gratuitous Permit No. R13-2022-09 from the Department of Environment and Natural Resources (DENR). Communication letters were also given to the barangay captains of each study area to request approval and assistance during sampling.

Sampling Design

The study used transect and quadrat sampling. A 2 km transect was established at each sampling site. When the transect line was caught along a forest trail, it extended 3-5 meters; in rivers, it extended at least 10 metres. Quadrat distances ranged from 150-200 m. Nine 10 x 10 m^2 quadrats per site along the transect line were established to account for erect pteridophytes >1 m tall, such as *Cyathea*, *Sphaeropteris*, and *Dicksonia*. A smaller 1 x 1 m^2 quadrat was established for herbaceous pteridophytes <1 m tall within the main quadrat. All pteridophytes within the quadrats were manually counted. The sampling design, including quadrat sizes and transect line length, was adapted from the Philippine Biodiversity Assessment Monitoring System (BAMS) manual, with modifications (BMB-GIZ 2017).

An opportunistic survey technique and repeated transect walks were also conducted to complement species richness findings and create a comprehensive list of species. Opportunistic surveys use a non-random survey method, selecting available and accessible samples for data collection (Brown & Williams 2019).

Collection, Processing, Documentation, and Identification of Specimens

For herbarium vouchers and species identification, knife and pruning shears were used to collect fertile fern duplicates. To collect the smaller ferns, the entire plant was uprooted, the soil was removed, and the plant was pressed (Sezate et al. 2024). Complete arborescent fern fronds were collected and cut into pieces. The epiphytic pteridophytes were collected by climbing trees and cutting branches. The plant species were placed on a piled newspaper. Non-pressed field samples were permanently stored in a plastic bag in a denatured alcohol-filled icebox. Data such as collection number, habitat, collection date, attributes, and features were coded on specimens. Pteridophyte samples were processed using the wet method for plants (Coritico et al. 2020). All pteridophytes were documented at established sites. Each species was photographed for its growth forms (terrestrial, epilithic, epiphytic, aquatic, semi-aquatic, and arborescent), fertile leaves/fronds, sori arrangement, and frond focus. For safety reasons, only low trunk epiphytes (>3-5 m above the host tree) were recorded. An organized field diary recorded all important events, notes, and observations. Preliminary identification in the field was conducted by using prepared images. Herbarium vouchers, online database, and other publications: Copeland (1958), Zamora and Co (1986), Hoovenkamp et al. (1998), Fernando (2007), and Pelser et al. (2011 onwards) and electronic specimen photographs from Global Plants on JSTOR were used to identify and describe plants. Pteridophyte taxonomists from the Center of Biodiversity Research and Extension in Mindanao (CEBREM) were also consulted for species identification and verification.

Data Analysis

Species richness and abundance of ferns and lycophytes were quantified in each sampling quadrat. Palaeontological Statistics Software (PAST) was used to analyse the diversity indices such as species richness, dominance, evenness, Shannon-Weiner Index, and Simpson Index (Hammer et al. 2001). Statistical differences in species diversity values between the APL sampling sites were analysed using one-way ANOVA in R software version 4.2.1.

Plymouth Routines in Multivariate Ecological Research (PRIMER) software version 6 was used to analyse the community structure of pteridophytes (Clarke & Gorley 2005; Along et al. 2020). Non-parametric multivariate analyses, including non-metric multidimensional scaling (nMDS), one-way Analysis of Similarities (ANOSIM), and Similarity Percentages (SIMPER), were performed in PRIMER v6 software (Sutomo & Van Etten 2023). A Bray-Curtis resemblance matrix (species and site) on pre-treated abundance data was ordinated using nMDS to visualise the community structure of pteridophytes across sampling sites (Somerfield et al. 2021; Sutomo & Van Etten 2023). One-way ANOSIM was used to analyse the dissimilarities in pteridophyte assemblages across sampling sites. Furthermore, the species' average contribution to site dissimilarity was calculated in terms of percent using SIMPER (Cano-Mangaoang 2020). Different parameters for measuring the magnitude and importance of ferns and lycophytes were also used, including absolute frequency, relative frequency, density, relative density, and species importance value (SIV) (Nguyen et al. 2014).

RESULTS AND DISCUSSION

Composition and Richness of Pteridophytes

Sixty-nine (69) species, belonging to 19 families and 34 genera of ferns and lycophytes, were recorded in the Andanan Protected Landscape (APL), Northern Mindanao, Philippines (Table 1). Sixty-three (63) species were ferns, and six (6) were lycophytes. This number of species constitutes about 6.27 % of the identified Philippine pteridophytes. Among the families, Polypodiaceae had the most species (12 species, 17 %) – followed by Pteridaceae (9 species, 13 %), and Tectariaceae and Thelypteridaceae (8 species each, 12 %) (Figure 2). Conversely, the genera with the highest frequency of occurrence were *Asplenium* (7 species), *Tectaria* (6 species), *Pteris* (5 species), *Selaginella* (4 species), and *Pyrrosia* (4 species). Several ferns and lycophytes documented in the APL are shown in Figure 3.

Based on the IUCN Redlist of Threatened Species and DAO 2017-11, APL had nine (9) threatened pteridophytes. This represents 11.59 % of species documented. Three species were classified as vulnerable, three endangered, two Other Threatened Species (OTS), and one near threatened (NT) (Table 1). Additionally, two species (2.90 %) were endemic to the Philippines: *Chingia christii* (Copel.) Holttum and *Pyrrosia splendens* (C.Presl) Ching. Notable species include *Drynaria heraclea* (Kunze) T.Moore, *Angiopteris evecta* (G.Forst.) Hoffm., *Ceratopteris thalictriodes* (L.) Brongn., *Microlepia speluncae* (L.) T.Moore, *Davallia solida* (G.Forst.) Sw., *Phlegmariurus squarrosus* (G.Forst.) Á.Löve & D.Löve., and *Psilotum nudum* (L.) P.Beauv.

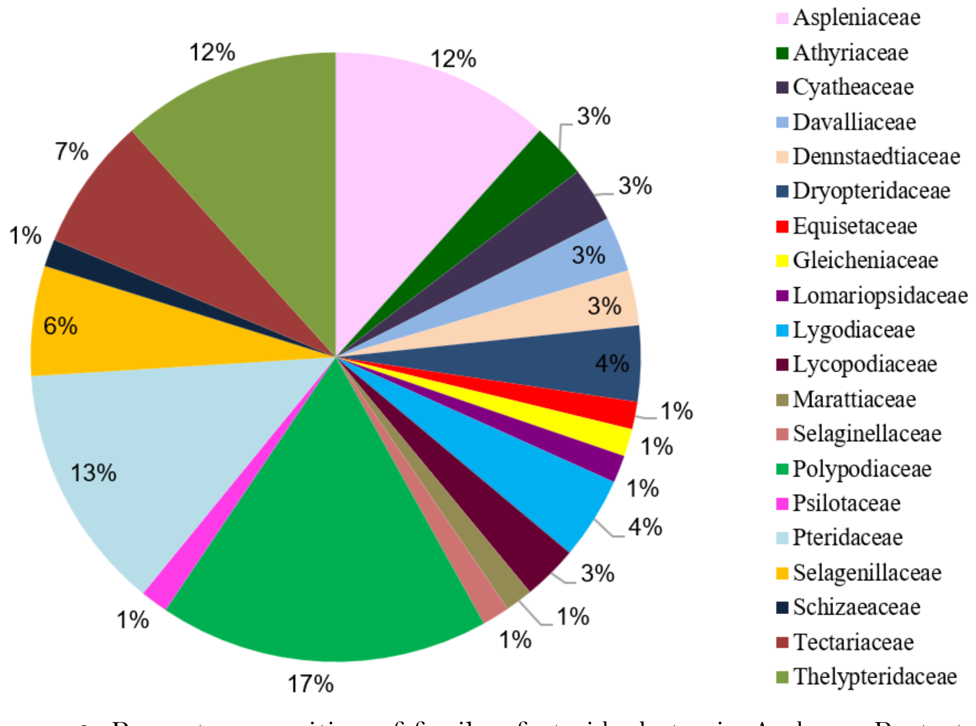

Figure 2. Percent composition of family of pteridophytes in Andanan Protected Landscape (APL).

The dominant families of pteridophytes recorded in the APL are also widely distributed on the island of Mindanao (Amoroso et al. 2012, 2015b; Coritico et al. 2020; Cudal et al. 2021; Rufila et al. 2022; Bada et al. 2023). These are the same families of ferns that have the largest number of species in the Philippines (Alcala et al. 2019; Lillo et al. 2020). The majority of species in tropical Asian countries, especially in Southeast Asia (SEA), such as Indonesia (Sofiyanti 2019), Thailand and Vietnam (Chen et al. 2017), Malaysia (Maideen et al. 2019), Bangladesh (Haque et al. 2017), and Myanmar (Khine et al. 2017), also belong to the families Aspleniaceae, Polypodiaceae, Pteridaceae, and Thelypteridaceae. Additionally, these families are widespread in tropical America, including Mexico (Acebey et al. 2017) and Brazil (Matos et al. 2020). Furthermore, these fern families are cosmopolitan, meaning they are widely distributed globally (Wolf et al. 2015). Floristic research on vascu-

Table 1. Checklist, distribution, conservation status, and growth forms of ferns and lycophytes in the Andanan Protected Landscape (APL), Caraga Region, Philippines.

Family	Species Name	Distribution and Conservation Status	Growth Forms	Calaitan	Berseba	Ararat
Aspleniaceae	*Asplenium anisodontum* C.Presl	Na	TE	+	-	+
	Asplenium haenkei Copel.	Na	TE	-	-	+
	Asplenium nidus L.	Na	EP/LI	+	+	+
	Asplenium polyodon G.Forst.	Na	TE	-	-	+
	Asplenium scandens J.Sm. ex Houlston & T.Moore	Na	EP	-	-	+
	Asplenium sp. 1	-	TE	-	-	+
	Asplenium sp. 2	-	LI	-	-	+
Athyriaceae	*Diplazium esculentum* (Retz.) Sw.	Na	TE	+	+	+
	Diplazium sp.	-	TE	+	+	+
Cyatheaceae	*Sphaeropteris glauca* (Blume) R.M.Tryon	Na, EN[a]	AR	+	+	+
Davalliaceae	*Davallia repens* (L.f.) Kuhn	Na	EP	+	-	-
	Davallia solida (G.Forst) Sw.	Na, OTS[a]	EP	+	-	+
Dennstaedtiaceae	*Microlepia speluncae* (L.) T.Moore	Na, NT[b]	TE	+	-	+
	Pteridium aquilinum (L.) Kuhn	Na	TE	-	+	+
Dryopteridaceae	*Bolbitis* sp.	-	TE	-	-	+
	Pleocnemia cumingiana C.Presl	Na	AR	+	+	+
	Pleocnemia irregularis (C.Presl) Holttum	Na	TE	+	+	+
Equisetaceae	*Equisetum ramosissimum* Desf.	Na	TE/SA	+	-	+
Gleicheniaceae	*Dicranopteris linearis* (Burm.f.) Underw.	Na	TE	-	+	-
Lomariopsidaceae	*Cyclopeltis crenata* (Fée) C.Chr.	Na	LI	+	-	+
Lygodiaceae	*Lygodium circinnatum* (Burm.f.) Sw.	Na	TE	-	+	+
	Lygodium japonicum (Thunb.) Sw.	Na	TE	-	-	+
Lycopodiaceae	*Palhinhaea cernua* (L.) Vasc. & Franco	Na	TE	-	-	+
	Phlegmariurus squarrosus (G.Forst.) Á.Löve & D.Löve	Na, EN[a]	EP	-	-	+
Marattiaceae	*Angiopteris evecta* (G.Forst.) Hoffm.	Na, OTS[a]	TE	+	+	+
Nephrolepidaceae	*Nephrolepis hirsutula* (G.Forst.) C.Presl	Na	TE	+	+	+
	Nephrolepis sp.	-	TE	-	-	+
Pteridaceae	*Antrophyum semicostatum* Blume	Na	LI	-	-	+
	Antrophyum sessilifolium (Cav.) Spreng	Na	EP	+	-	+
	Ceratopteris thalictroides (L.) Brongn.	Na, EN[a]	SA/A	+	-	-
	Pityrogramma calomelanos (L.) Link	Nt	TE	+	+	-
	Pteris ensiformis Burm.f.	Na	TE	-	+	+
	Pteris glaucovirens Goldm.	Na	TE	+	+	+
	Pteris oppositipinnata Fée	Na	LI	+	-	-
	Pteris tripartita Sw.	Na	TE	+	+	-
	Pteris vittata L.	Na	TE	+	+	-
Polypodiaceae	*Drynaria heraclea* (Kunze) T.Moore	Na, VU[a]	EP	-	-	+
	Drynaria quercifolia (L.) J.Sm.	Na	EP	+	+	+
	Lepisorus longifolius (Blume) Holttum	Na	EP	-	-	+
	Lepisorus mucronatus (Fée) Li Wang	Na	EP	+	-	+
	Microsorum congregatifolium (Alderw.) Holttum	Na	EP/LI	+	+	+
	Microsorum scolopendria (Burn.f.) Copel.	Na	TE/EP	-	-	+
	Phymatosorus membranifolius (R.Br.) S.G.Lu	Na	TE	-	-	+
	Platycerium bifurcatum (Cav.) C.Chr.	Nn	EP	-	-	+
	Pyrrosia nummulariifolia (Sw.) Ching	Na	EP	-	-	+
	Pyrrosia piloselloides (L.) M.G.Price.	Na	EP	+	+	-

Table 1. Contd.

Family	Species Name	Distribution and Conservation Status	Growth Forms	Calaitan	Berseba	Ararat
	Pyrrosia sp.	-	TE	+	-	+
	Pyrrosia splendens (C.Presl) Ching	PE, VU[a]	EP	-	-	+
Psilotaceae	*Psilotum nudum* (L.) P.Beauv.	Na, VU[a]	TE	+	-	+
Selaginellaceae	*Selaginella aenea* Warb.	Na	TE	+	+	+
	Selaginella biformis A.Braun ex Kuhn	Na	TE	-	-	+
	Selaginella engleri Hieron.	Na	TE	+	+	+
	Selaginella remotifolia Spring	Na	LI	-	-	+
Schizaeaceae	*Schizaea dichotoma* (L.) Sm.	Na	TE	-	-	+
Tectariaceae	*Tectaria angulata* (Willd.) Copel.	Na	TE	-	-	+
	Tectaria decurrens (C.Presl) Copel.	Na	TE	+	-	-
	Tectaria melanocaula (Blume) Copel.	Na	TE	-	-	+
	Tectaria nayarii Mazumdar	Na	TE	-	-	+
	Tectaria polymorpha (Wall. ex Hook.) Copel.	Na	TE	+	+	+
	Tectaria sp.	-	TE	+	-	-
Thelypteridaceae	*Chingia christii* (Copel.) Holttum	PE	TE	-	+	+
	Christella parasitica (L.) H.Lév. ex Y.H.Chang	Na	TE	+	+	+
	Christella sp.	-	TE	-	+	-
	Macrothelypteris torresiana (Gaudich.) Ching	Na	TE	+	+	+
	Pronephrium sp.	-	TE	-	-	+
	Sphaerostephanos latebrosus (Kunze ex Mett) Holttum	Na	TE	+	-	-
	Sphaerostephanos sp.	-	TE	-	+	-
	Strophocaulon unitum (L.) S.E.Fawc. & A.R.Sm.	Na	TE	+	+	+
Total number of species per site:				**37**	**28**	**56**

Note: *Endemism:* PE= Philippine Endemic, Na=Native, Nt=Naturalized, Nn=Non-native; *Conservation Status:* EN=Endangered, VU=Vulnerable, NT=Near Threatened, OTS=Other Threatened Species, [a]=DAO 2017-11, [b]=IUCN; *Growth forms:* EP= Epiphytic, LI= Lithophytic, TE= Terrestrial, AR=Arborescent, SA=Semi-aquatic, A=Aquatic; Present (+), Absent (-).

lar plants identified members of these pteridophyte groups in the Caraga region (Along et al. 2020; Sarmiento et al. 2022).

Among the noteworthy species are a few individuals of the vulnerable species *Drynaria heraclea* (Kunze) T.Moore and *Pyrrosia splendens* (C.Presl) Ching, recorded in Mt. Ararat. This site has one of the remaining intact forests in the APL. This forest experiences minimal human disturbance and habitat fragmentation and, hence, offers a stable and unaltered environment that can support a diversity of species, including those with specialised habitat requirements. *C. thalictriodes* (L.) Brongn. was also documented near the Andanan River in Calaitan, while *P. nudum* (L.) P.Beauv. was found in Calaitan and Mt. Ararat. However, these floral species are prone to over-collection and exploitation, especially those unique-looking ferns and lycophytes such as *P. squarrosus* (G.Forst.) Á.Löve & D.Löve and *D. heraclea* Copel. Plant poaching occurs primarily for ornamental use and for sale in floral markets and gardens.

These noteworthy species reflect the importance of pteridophyte diversity in the APL. Many noteworthy species are threatened or endangered, and

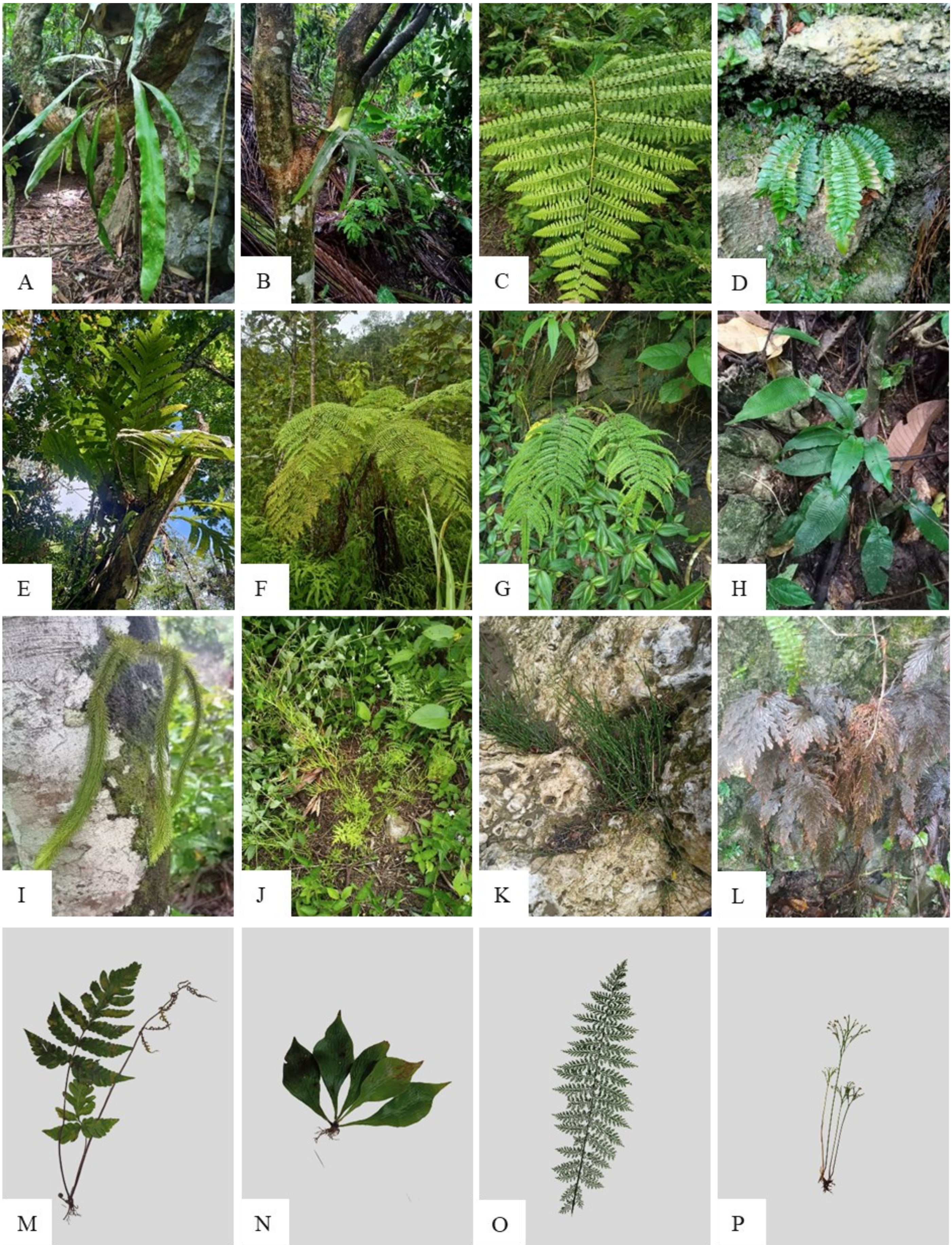

Figure 3. Some pteridophytes in Andanan Protected Landscape (APL), Caraga Region, Philippines. (A) *Pyrrosia splendens*, (B) *Platycerium bifurcatum*, (C) *Microlepia speluncea*, (D) *Cyclopeltis crenata*, (E) *Drynaria heraclea*, (F) *Sphaeropteris glauca*, (G) *Pteris opposipinnata*, (H) *Pronephrium* sp. (I) *Phlegmariurus squarrosus*, (J) *Ceratopteris thalictriodes*, (K) *Equisetum ramosissimum*, (L) *Selaginella biformis* (M)*Tectaria nayarii*, (N) *Antrophyum semicostatum*, (O) *Asplenium scandens*, and (P) *Schizaea dichotoma*.

their preservation is crucial for ecosystem functioning. Protecting these species helps prevent the loss of genetic diversity (Barcelona 2005), which is vital for the long-term survival of many other species and human interests such as medicine and agriculture. The presence of *P. bifurcatum* (Cav.) C.Chr. in one of the agroforests in Mt. Ararat is also notable. The Philippines has only two identified species of Staghorn ferns— *Platycerium coronarium* (J.Koenig ex O.F.Müll.) Desv. and *Platycerium grande* (A.Cunn. ex Hook.) J.Sm.; hence the presence of *P. bifurcatum* (Cav.) C.Chr. in a forested area is unlikely. However, this staghorn fern is commonly cultivated and used as an ornamental garden plant. The documented *P. bifurcatum* (Cav.) C.Chr. may be planted and cultivated in the area and occurs with human influence. The diversity of species may be affected by the sampling area's size and accessibility, soil composition, climate conditions, and anthropogenic activities such as deforestation for agriculture or industrial purposes and land pollution (Amoroso et al. 2016; Coritico et al. 2017). Geographic position affects climate, habitat diversity, latitude, altitude, isolation, and historical factors, which can also affect species richness (Jones et al. 2013). Climate variations across latitudes and altitudes create different ecological niches, with tropical regions having more species due to stable conditions and longer evolutionary histories. The relatively high species richness of pteridophytes observed in APL may be due to different land use, vegetation, and forest types, as well as the environmental factors in the area. This observation has significant implications for strengthening the ecological structure of the forest.

Growth form

Pteridophytes exhibit a variety of growth forms adapted to different types of environments. Existing literature on Philippine pteridophytes guided the classification of growth forms (Coritico et al. 2020; Pescuela et al. 2024). Most of the recorded pteridophyte species were terrestrial (48 species, 69 %) — followed by epiphytes (12 species, 17 %), lithophytic (6 species, 9 %), arborescent (2 species, 3 %), and aquatic and semi-aquatic (1 %) (Table 1). Other species were observed that have more than one habitat type. *Ceratopteris thalictriodes* (L.) Brongn. and *Equisetum ramosissimum* Desf can be terrestrial or aquatic/semi-aquatic. *Asplenium nidus* L. and *Microsorum congregatifolium* (Alderw.) Holttum can produce epiphytes on trees and lithophytes simultaneously, while *Microsorum scolopendria* (Burn.f.) Copel. can grow terrestrially and as an epiphyte.

The growth forms showed that the pteridophytes are mainly terrestrial, with a sufficient source of nutrients from soil and water. They were located mainly under the shade of canopy trees. Another reason is that terrestrial species have significantly more tolerance than other species (Watkins et al. 2007). Terrestrial species also tend to receive sufficient resources for primary reproduction, such as water and soil nutrients (Soons et al. 2017; Hunter et al. 2021). Pteridophytic epiphytes abundant in the area includes *Asplenium nidus* L. and *Drynaria quercifolia* (L.) J.Sm., *Pyrrosia splendens* (C.Presl.) Ching, and *Microsorum congregatifolium* (Alderw.) Holttum. The number of epiphytic species is primarily due to the numerous trees on which they can latch. However, epiphytic species are less stable than terrestrial habitats and more susceptible to catastrophic, natural, or anthropogenic disturbances (Watkins et al. 2007). The degradation of canopy and epiphytic habitats is pronounced and more affected than other habitat types (Zotz 2016). Epiphytic species also encountered increased competition from bryophytes (Mizuno et al. 2015). Furthermore, epiphytic plant habitats exhibit lower water and nutrient retention than terrestrial ecosystems (Lu et al. 2015). These findings demonstrate that disturbances, whether directly or indirectly linked to habitat tolerance, play a critical role.

Species Diversity

The APL has a Shannon-Weiner Index (H') and Simpson Index (D) values of 3.65 and 0.96, respectively, which indicates relatively high pteridophyte diversity based on the Fernando Biodiversity Scale (1998) and Simpson (1949). Species richness of pteridophytes significantly varies in the three areas (F value = 7.62, $p<0.05$; Figure 4A). Other diversity measures, including abundance, dominance, evenness, Shannon-Weiner Index, and Simpson's Index, revealed no significant variations among the three locations (Figure 4B-F). Among the sampling sites, Mt. Ararat was revealed to have the highest pteridophyte diversity (H'=3.4) in APL as well as species richness, and abundance, whereas lowest in species evenness. Conversely, Berseba has a total Shannon diversity of H'=2.821, making the area the least diverse.

The considerable variety of pteridophyte species found on Mt. Ararat may be due to its mid-elevation and the ruggedness of the topography as altitude increases. The mid-elevation peak hypothesis suggests that moderate elevations have the most diverse environmental conditions, supporting a wider range of niche-adapted species (Rana et al. 2019). Meanwhile, *Selaginella engleri* Hieron., *Nephrolepis hirsutula* (G.Forst.) C.Presl, *Diplazium esculentum* (Retz.) Sw., and *Dicranopteris linearis* (Burm.f.) Underw. have dominated Berseba in greater numbers than other species, reducing species diversity. Its lower diversity indices may be due to human disturbances. Because environmental variance in tropical rainforests reduces habitat stability, the severity of disruption may have a direct impact on species diversity (Abas 2017; Gutiér-

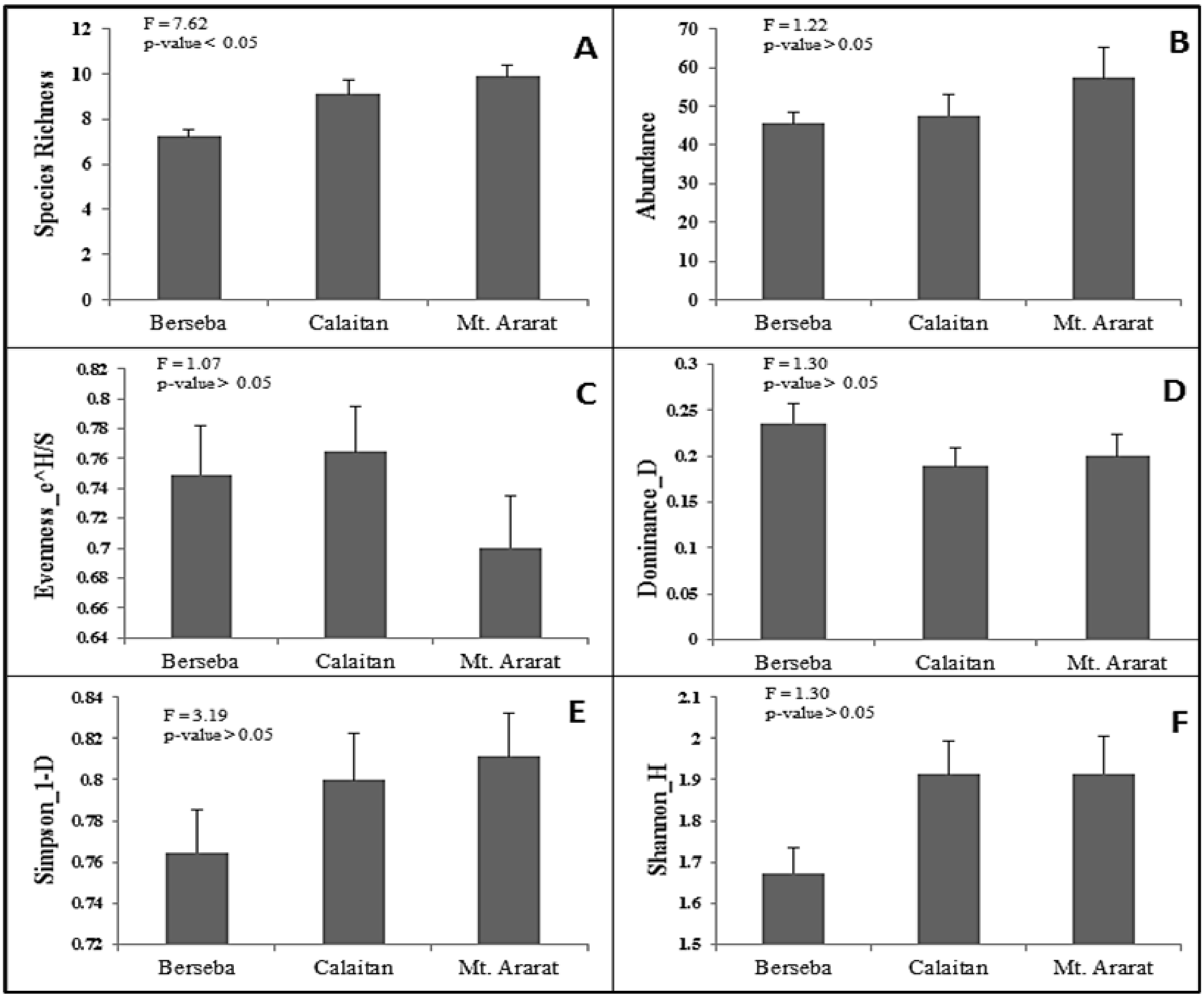

Figure 4. Comparison of ferns and lycophytes diversity indices in the three selected areas in APL, Bayugan City, Agusan del Sur. (A) Species Richness, (B) Abundance, (C) Evenness (D) Dominance, (E) Simpson's Index, (F) Shannon-Weiner Index. One Way ANOVA results (F ratios and significance levels) for comparing site diversity attributes. Error bars showed the standard error of the mean (n=9).

rez-Lozano et al. 2017).

Several biological and physical factors affect a species' ability to thrive in forests, grasslands, wetlands, and urban habitats (James 2018). The absence of plant competitors and ideal environmental conditions would favour species growth and reproduction. Pteridophytes are more abundant in Mt. Ararat due to their diverse forest types, cool, humid climate, and suitable habitats. Another factor may be the greater availability of host plant rocks, boulders, and trunks for epiphytic pteridophytes. The absence of epiphytes above the tree line is due to a lack of suitable substrate or trees, not to environmental factors (Zotz et al. 2014). Deforestation and clearing the ground cover may also be factors since Berseba has become agricultural land. These activities show how forest fragmentation and land conversion affect pteridophyte diversity and ecosystem flora and fauna (Stiremen 2014; Zambrano et al. 2019; Cano-Mangaoang 2020). It also shows tropical montane forests are losing habitat (Baynes et al. 2016) and being replaced by other land uses. Ecological specialist pteridophytes have more microenvironments on steeper slopes (Park et al. 2020; Young 2021). These areas have unique environmental conditions that support a unique species composition. However, steep topography is more susceptible to soil erosion, landslides, and natural disturbances, as seen in Berseba, where soil erosion has damaged several pteridophyte habitats.

Species Importance Value

The species with the highest Species Importance Value (SIV) in the APL include *Selaginella engleri* Hieron. (12.77), followed by *Nephrolepis hirsutula* (G.Forst.) C.Presl (11.91), and *Angiopteris evecta* (G.Forst.) Hoffm (11.06) (Table 2). Terrestrial ferns are the most abundant species in all sampled areas of the APL. They are light-tolerant species and can also thrive in moderate to low light conditions (Anderson 2021). They spread rapidly by underground creeping rhizomes or sporadically (Heim 2015). They also colonise disturbed areas at one stage in succession (Kessler 2014). Both *S. engleri* Hieron. and *N.*

Table 2. The most dominant pteridophyte species with the highest Species Importance Value (SIV) in Andanan Protected Landscape, Caraga Region, Philippines.

Species of Pteridophytes	Species Importance Value (SIV)	Rank
Selaginella engleri Hieron.	12.77	1
Nephrolepis hirsutula (G.Forst.) C.Presl.	11.91	2
Angiopteris evecta (G.Forst.) Hoffm.	11.06	3
Diplazium sp.	10.21	4
Asplenium nidus L.	8.51	5
Christella parasitica (L.) H.Lév. ex Y.H.Chang.	7.66	6
Sphaerostephanos unitus (L.) Holttum	7.66	
Pteris tripartita Sw.	5.96	7
Sphaeropteris glauca (Blume) R.M.Tryon	5.96	
Asplenium polyodon G.Forst.	5.11	8
Pteris glaucovirens Goldm.	5.11	
Selaginella cupressina (Willd.) Spring	5.11	
Pleocnemia cumingiana C.Presl	5.11	
Macrothelypteris torresiana (Gaudich.) Ching	4.26	9
Drynaria quercifolia (L.) J.Sm.	3.40	10
Antrophyum semicostatum Blume	3.40	

hirsutula (G.Forst.) C.Presl are commonly distributed and naturalised terrestrial pteridophytes in secondary forests.

Additionally, *Angiopteris evecta* (G.Forst.) Hoffm has the potential to colonise new ecosystems readily. Among the areas studied, these three species have a high affinity to the understory and disturbed sites. This may explain their high species importance value like others. Apart from bryophytes, they colonised or recolonised disrupted areas, indicating their biological importance. Moreover, the removal of these species would significantly impact vegetation dynamics. These pteridophyte species can serve as indicators of understory disturbance or habitat quality based on ecological data (Abas 2017; Della & Falkenberg 2019).

Community Structure of Pteridophytes

The overall result of ANOSIM based on species similarity generated a Global R-value of 0.305 (p-value<0.01), indicating a high similarity with some overlap of pteridophyte communities across sampling sites (Figure 5). The non-metric multidimensional scaling (nMDS) plot showed a moderate overlap between the Berseba and Calaitan plots, indicating some level of species composition similarity. Conversely, Mt. Ararat plots are generally more separated from Berseba and Calaitan samples, indicating distinct species compositions. At 15 % Bray Curtis similarity, the nMDS ordination formed three major assemblage patterns of plots based on pteridophyte abundance. All plots in Calaitan and Berseba and three (3) plots in Mt. Ararat formed the largest assemblage A. Assemblage B includes most of the plots from Mt. Ararat (5 plots and 1 from Berseba). Assemblage C contains one plot each from Calaitan and Mt. Ararat. MP4 from Mt. Ararat is the most distinct, showing the least similarity to all other plots, and indicating a significantly different species composition. Further, a 15 % similarity highlights groups of plots that share at least 15 % of their species composition. A lower similarity percentage (15 %) helps identify broader patterns and understand the spatial relationships of pteridophytes within the nMDS plot without overwhelming the plot with too many clusters.

Similarity percentage (SIMPER) analysis was used to assess which species account for most of the observed variations between sampling sites. The species *Selaginella engleri* Hieron. (37.42 %), *Strophocaulon unitum* (L.) S.E.Fawc. & A.R.Sm. (22.63 %), and *Asplenium polyodon* G.Forst. (27.55 %) had the highest percentage contribution to the dissimilarity of pteridophytes within Berseba, Calaitan, and Mt. Ararat, respectively. Meanwhile, *S. engleri* Hieron., *S. unitum* (L.) S.E.Fawc & A.R.Sm., and *N. hirsutula* (G.Forst.) C.Presl are the top three species contributing 22 % to the dissimilarity between Berseba and Calaitan; *S. engleri* Hieron., *N. hirsutula* (G.Forst.) C.Presl and *A. polyodon* G.Forst. contributed 19 % to the dissimilarity between Berseba and Mt. Ararat; and *S. unitum* (L.) S.E.Fawc. & A.R.Sm., *S. engleri* Hieron., and *A. polyodon* G.Forst. contributed 16 % to the dissimilarity between Calaitan and Mt. Ararat. Notably, the highest average dissimilarity (88.5 %) of pteridophyte communities was found between Calaitan and Mt. Ararat.

The main reason behind the similarity of Assemblages A, B, and C is the common species shared between sites such as *Nephrolepis hirsutula* (G.Forst.) C.Presl, *Asplenium polyodon* G.Forst, *Christella parasitica* (L.) H.Lév. ex Y.H.Chang, *Pteris tripartita* Sw., *Asplenium nidus* L., *Strophocaulon unitum* (L.) S.E.Fawc. & A.R.Sm., *Angiopteris evecta* (G.Forst.) Hoffm, and *Selaginella engleri* Hieron. Another reason is that the areas are relatively close geographically, with no distinct barriers to sharing similar species.

The minimal separation of sampling sites, as reflected in nMDS is likely due to differences in vegetation characteristics. Calaitan and Berseba, which comprise mostly the assemblage A is characterised by an array of forest segments where various discrete patches of forested areas are scattered or distributed across the area, often intermixed with other land uses or ecosystem types such as agroforest and plantations. The common species found in the area are *Sphaeropteris glauca* (Blume) R.M.Tryon, *Angiopteris evecta* (G.Forst.) Hoffm., *Nephrolepis hirsutula* (G.Forst.) C.Presl, *Pteris glaucovirens* Goldm. ex Hieron., *Drynaria quercifolia* (L.) J.Sm., *Microsorum congregatifolium* (Alderw.) Holttum, *Selaginella aenea* Warb., *Selaginella engleri* Hieron., *Tectaria polymorpha* (Wall. ex Hook.) Copel., *Strophocaulon unitum* (L.) S.E.Fawc & A.R.Sm., and *Christella parasitica* (L.) H.Lév. ex Y.H.Chang. The areas are disturbed minimally by anthropogenic activities, allowing for the survival of more resistant pteridophyte species. In contrast, Mt. Ararat, which composed mostly the assemblage B has advanced secondary forest characteristics dominated by Dipterocarps and other lowland forest species, less disturbance, and varied microhabitats (e.g. riparian, rocks), which allow various species of pteridophytes to thrive in the understory vegetation. The distinct species composition in plot 4 of Mt. Ararat can be attributed to being an old-growth forest with fewer understory species. It was dominated by the creeping lycophyte species *Selaginella biformis* A.Braun ex Kuhn and *Selaginella remotifolia* Spring, which require humid and shaded conditions to grow abundantly. Additionally, these species were unshared from other plots in Mt. Ararat or other study sites.

In species assemblage theory, species coexisting across multiple study sites indicates adaptation to similar environmental gradients and habitat conditions, while proximity and connectivity between sites enable species movement and colonisation (Delanda 2016). Additionally, a species' presence in an area highlights the impact of microhabitat conditions such as humidity and shade (Senior et al. 2017). Limited-distribution species are rare, whereas widespread species are common (Pimm et al. 2014; Dallas et al. 2017). Most pteridophytes shared across APL sampling sites are both abundant and widely distributed. Soil nutrients such as phosphorus and nitrogen support plant

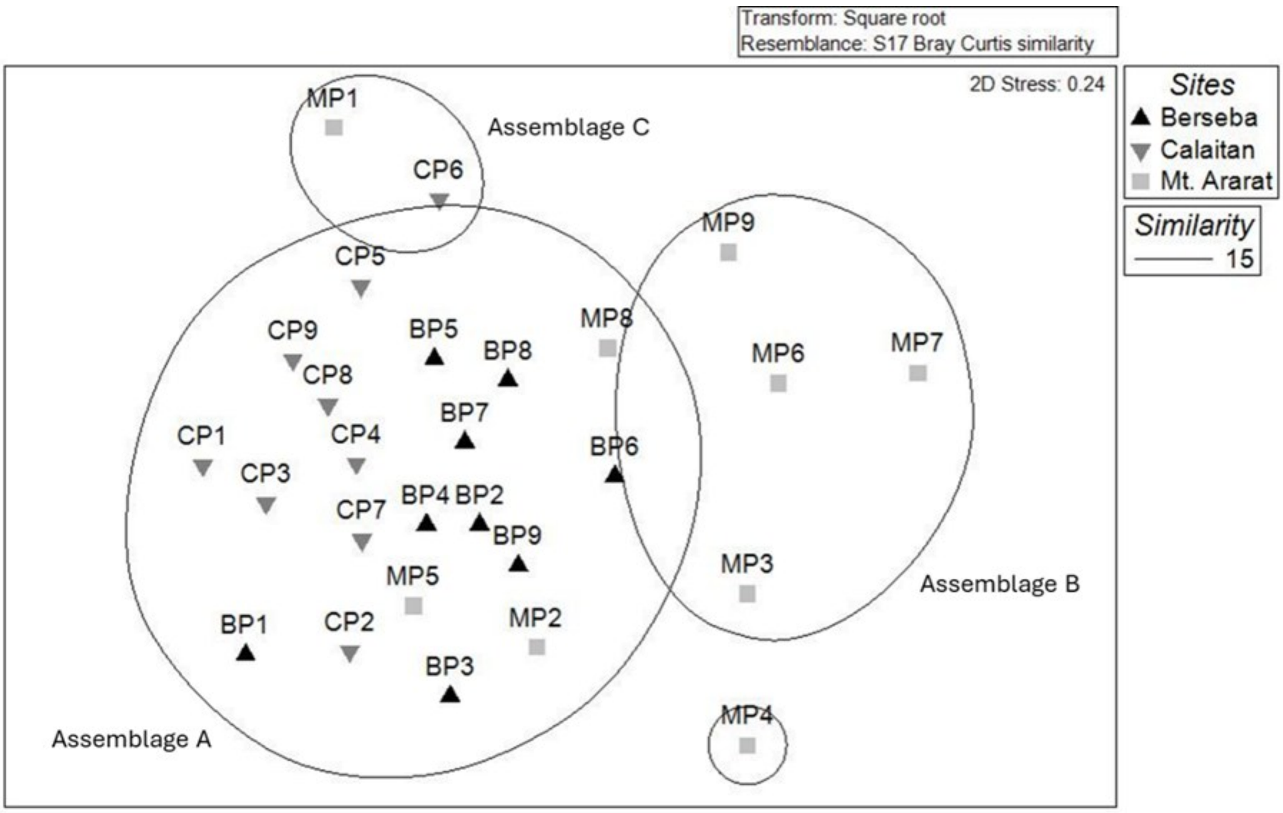

Figure 5. Non-metric multidimensional scaling (nMDS) of Bray Curtis similarities based on square root transformed abundances of pteridophyte taxa across three sample sites. C-Calaitan, Site 1; M-Mt. Ararat, Site 2; B-Berseba, Site 3; and P-plot.

growth (Ye et al. 2022). When a species can no longer partition space according to its niche requirements, removing nutrition reduces species coexistence. Causal mechanisms within a species determine its abundance and distribution (Ehrlén & Morris 2015).

CONCLUSIONS

This study provides a preliminary checklist and valuable insights into the distribution of pteridophytes within a protected forest landscape in Northeastern Mindanao, Philippines. The significant species richness and diversity of pteridophytes, including conservation priority species that are both endemic and threatened, within the Andanan Protected Landscape (APL), indicate the area's importance for the conservation and preservation of these plant communities. The baseline information provides data support for the management plans and conservation initiatives of APL's protected area managers. In light of increased anthropogenic habitat modification and degradation, we strongly advocate for ongoing surveys and systematic evaluations of the conservation status of pteridophytes within the protected forest landscape. Further research is needed to determine the relationship between environmental conditions and the abundance, diversity, and spread of pteridophytes.

AUTHOR CONTRIBUTION

Conceptualisation, H.J.S., A.A., M.D., and R.L.; Methodology, A.A., M.D., and R.L.; software, A.A.; Validation, A.A., M.D., and R.L.; Formal analysis, H.J.S. and A.A.; Investigation, H.J.S. and A.A.; Resources, H.J.S.; Data curation, H.J.S. and A.A.; Writing¾original draft preparation, H.J.S.; Writing¾ review and editing, A.A., M.D., and R.L., Visualisation, A.A.; Supervision, A.A., M.D., and R.L. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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