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Identification of Pteridophyte plant species on the southeast slope of Mount Merapi National Park, Kemalang, Central Java, Indonesia

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Abstract. *Fatin SK, Wijayanti S, Khoirunnisa S, Wela SMD, Sholiqin M, Setyawan AD. 2025. Identification of pteridophyte plant species on the southeast slope of Mount Merapi National Park, Kemalang, Central Java, Indonesia. Asian J Environ 1: 31-43.* This study aimed to identify and analyze the diversity of Pteridophytes on the southeastern slope of Mount Merapi National Park, Central Java, Indonesia. Field surveys recorded a total of 31 species from 14 families and 2,075 individuals, demonstrating the importance of this volcanic montane area as a habitat for ferns. The most abundant family was Pteridaceae, with *Deparia petersenii* (Kunze) M.Kato and *Christella subpubescens* (Blume) Holttum as the dominant species, while *Platycerium bifurcatum* (Cav.) C.Chr. and *Elaphoglossum callifolium (*Blume) J.Sm.were the rarest taxa. Terrestrial ferns were the most common growth form, comprising 22 species and 93.9% of individuals, which reflects the suitability of the local abiotic environment characterized by high soil moisture (72.5%), neutral soil pH (7.15), moderate temperature (22.29 °C), and mid-elevation (1,213.5 masl). Biodiversity indices indicated moderate diversity (H′ = 2.77) and richness (Dmg = 3.93), but high evenness (E = 0.81), showing that despite the dominance of several colonizers, many species maintained stable populations. Conservation analysis revealed that only five species were categorized as Least Concern, while the majority were not yet evaluated by the International Union for Conservation of Nature. These results suggest that fern communities in Mount Merapi are structured by a few abundant generalists but rely on habitat heterogeneity to sustain rare specialists, highlighting the importance of conserving diverse microhabitats to maintain ecological resilience.

Keywords: Biodiversity, conservation, Mount Merapi National Park, Pteridophyta

INTRODUCTION

Mount Merapi is a mountain with an altitude of 2,968 meters above sea level. It is one of the most active volcanoes in Indonesia, located in Central Java and forming part of the Pacific *Ring of Fire* (Yudistira et al. 2020). The area has been designated as Mount Merapi National Park since 2004, covering approximately 6,410 ha and serving as a conservation forest that supports diverse ecosystems (Ariyanto 2015). Its humid montane climate and fertile volcanic soils create favorable habitats for various plant groups, including Pteridophyta. The southeast slope of Merapi, particularly in the Kemalang area of Klaten, Central Java, Indonesia represents one of the less studied sections of this national park, although it is ecologically significant due to its transitional position between lowland agricultural areas and montane forests.

Pteridophyta are plants with a group of plants that spread. It is recorded that in Indonesia more than 1,300 species of Pteridophyta from a total of 12,000 species in the world. These species occur in diverse habitats such as tropical forests, mountain slopes, coastal areas, and crater margins (Parra et al. 2015). Pteridophytes can grow terrestrially, epiphytically, lithophytically, or even in aquatic environments (Alamsyah and Pamungkas 2020). Ecologically, they function as producers, ground cover, and contributors to nutrient cycling, while also providing medicinal and ornamental value (Juliasih and Adnyana 2023; Della and Falkenberg 2019). The wide range of ecological functions makes ferns valuable as bioindicators of environmental quality, particularly in forest ecosystems where their abundance and diversity reflect humidity, canopy cover, and soil fertility.

In addition to their ecological significance, Pteridophyta have socio-economic importance. Several species are traditionally used as medicinal plants (Juliasih and Adnyana 2023), while others such as *Platycerium bifurcatum* (Cav.) C.Chr. and *Selaginella* sp. species are cultivated as ornamentals. Their dual role in ecological processes and human livelihoods highlights the necessity of integrating fern diversity into conservation planning.

However, Pteridophyta diversity is increasingly threatened by anthropogenic pressures. Global warming, land-use change, and habitat degradation have accelerated biodiversity loss, including among ferns (Yoro and Daramola 2020; Mina et al. 2021). This highlights the urgency of inventory and conservation research to ensure their sustainability. The slopes of Merapi are particularly vulnerable, as volcanic activity, agricultural expansion, and tourism development can alter microhabitats. Disturbances such as soil erosion, changes in water availability, and deforestation directly impact fern populations, which are highly dependent on stable humidity and shade.

Studies on Pteridophyta in Indonesia have reported high diversity across altitudinal gradients, demonstrating their sensitivity to microclimatic conditions (Nasrandi et al.

2022; Priambudi et al. 2022). Yet, most research has focused on other mountains such as Merbabu and Telomoyo in Central Java, or Belitung in Kepulauan Bangka Belitung, Indonesia (Fujiyanto et al. 2015; Astuti et al. 2017; Karim et al. 2022). For example, studies in Merbabu revealed variations in fern richness with elevation (Astuti et al. 2017), while research in Belitung highlighted the role of humid lowland forests in sustaining diverse fern assemblages (Priambudi et al. 2022). These findings underscore the importance of local inventories to capture habitat-specific diversity patterns.

Despite the ecological and conservation importance of Mount Merapi, systematic assessments of fern diversity within this national park remain scarce. Previous studies have largely addressed vegetation analysis in secondary forests or socio-economic impacts of eruptions (Haryadi and Sugiyarto 2019; Umaya et al. 2020), but comprehensive inventories of ferns, particularly on the southeast slope, are lacking. The Kemalang route is also increasingly developed as an ecotourism area (Fatimah 2017; Maghfiroh et al. 2023), creating additional pressure but also offering opportunities for conservation education if biodiversity data are available. This research gap constrains understanding of how volcanic landscapes influence fern diversity and how conservation strategies should be prioritized.

Therefore, this study aims to determine the biodiversity and conservation status of Pteridophyta in Mount Merapi National Park, Kemalang, Klaten, Central Java, Indonesia. The results are expected to provide baseline data for conservation strategies and management of fern diversity in volcanic mountain ecosystems. By combining field exploration, vegetation analysis, and evaluation of environmental factors such as soil pH, temperature, and humidity, this research contributes to filling critical data gaps. Furthermore, documenting species that are rare or limited in distribution can guide monitoring programs and support policy decisions for the sustainable management of Mount Merapi National Park.

MATERIALS AND METHODS

Study area

Sampling in this research was carried out in March 2024 in Sapuangin and Kalireno, Kemalang Subdistrict, Klaten District, Central Java Province, Indonesia (Figure 1). According to Widhiastuti in 2023 Sapuangin is located at an altitude of 1377 meters above sea level, at a distance of 11 km from sub-district capital-city and 25 km from the district capital and 3.7 km from peak of Merapi with an average humidity of 76.25%, an average temperature of 24°C. The second location, namely Kalireno, is lower than the first location with an altitude of 800 meters above sea level (mdpl) which is cooler with an average temperature of 20°C.

Procedures

Data collection on Pteridophyte species used exploration techniques (cruise method) (Ridhwan 2022). Data collection was carried out by recording on a tally sheet which contained the alleged species name, number of individuals, morphological characters, and habitat. The tools and materials used in this research were tally sheets, hygrometers, soil thermometers, and pH meters.

This research uses qualitative analysis methods and field observations with survey methods by purposive sampling based on the presence of Pteridophytes (Mayasari et al. 2022). The survey method uses purposive sampling, meaning that samples are taken by exploring the Sapuangin and Kalireno areas.

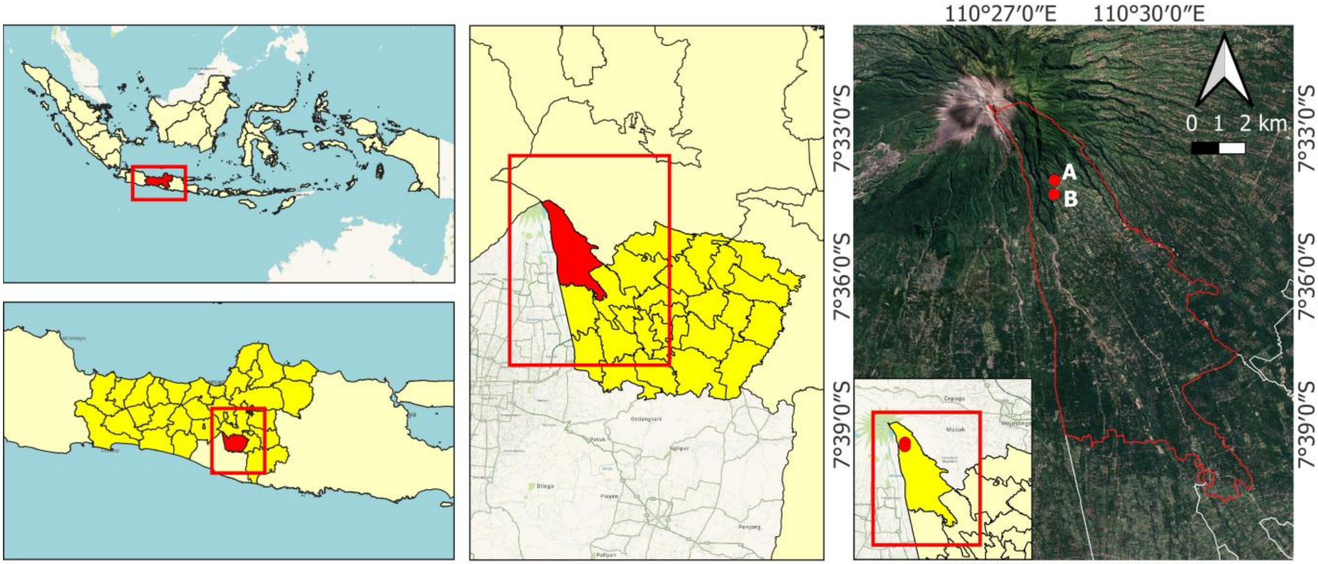

Figure 1. Research location, A. Sapuangin and B. Kalireno, Kemalang Sub-district, Klaten District, Central Java, Indonesia

Identification is carried out directly and indirectly. For unknown Pteridophyta species, their names will be identified using the book of Botany of Lower Plants (Hasanuddin and Mulyadi 2014), Types of Indonesian Ferns (LIPI 1980). Morphological details of generative (spores) and vegetative organs (leaves, stems, rhizomes, hairs/scales) were documented for each species found (Priambudi et al. 2022). Name validation is carried out by checking the scientific name on the Global Biodiversity Information Facility (GBIF) website (https://www.gbif.org/).

Data analysis

Data analysis was carried out by calculating the Shannon-Wiener Diversity Index, Margalef Species Richness Index, and Species Evenness Index, as well as identifying conservation status.

Shannon Wiener Diversity Index

Pteridophyta diversity was analyzed using the Shannon-Wiener Index. The formula for calculating the Wiener Shannon index:

$$H' = -\sum pi \ln pi$$

Where:
H' : Shannon-Wiener Diversity Index
ni : Number of individuals of the i-th species
n : Total number of individuals of all species
pi : ni/n

From the calculation results (H' value), it can be determined whether the area's species diversity level is high or low. Alwi et al. (2021) divide the level of species diversity where if:

$H' < 1$: Low species diversity.
$1 \leq H' \leq 3$: Moderate species diversity
$H' > 3$: High species diversity

Margalef species richness index

Pteridophyta species richness was analyzed using the Margalef Species Richness Index. The Margalef Species Richness Index of Margalef was calculated using the formula :

$$Dmg = \frac{S - 1}{lnN}$$

D : Margalef Species Richness Index
S : Number of species in the habitat
N : Total number of individuals of all species in the habitat

From the calculation results will be known the level of species richness. According to Wardhana et al. (2022), the criteria for the level of species richness are as follows:

$D < 2.5$: Low species richness level
$2.5 > D > 4$: Moderate species richness level
$D > 4$: High species richness level

Evenness diversity index

Evenness analysis of Pteridophyta was carried out using the evenness species Evenness Index. This index is calculated to determine the distribution of the number of individuals in each species (Salami and Akinyele 2018). The formula calculates the even species Evenness Index:

$$E = \frac{H'}{\ln S}$$

Where:
E : Evenness Index
H' : Diversity Index
S : Number of species

The Evenness Index value of the evenness type ranges from zero to one. The lower the value, the more unequal the number of individuals in each species. Conversely, the higher the value, the number of individuals distributed among species are even. Based on Rudianto et al. (2022), the species evenness category is based on the Evenness Index value, that is:

$E<0.4$: Small population uniformity
$0.4<E<0.6$: Average population uniformity
$E>0.6$: High population uniformity

RESULTS AND DISCUSSION

Biodiversity of pteridophytes

Total families, species, and individuals

The survey identified 31 species of Pteridophytes belonging to 14 families, with a total of 2,075 individuals (Table 1). This richness indicates that the southeastern slope of Mount Merapi provides a highly suitable environment for fern communities. The volcanic soils are porous, rich in minerals, and coupled with a neutral to slightly acidic pH (6.9-7.4), creating conditions favorable for nutrient uptake and spore germination (Saputro and Utami 2020). In addition, the area's moderate temperatures (20-24°C) and high soil moisture (69-76%) (data from field measurements) are critical abiotic factors that enhance fern abundance, since ferns rely on external water for fertilization and are highly sensitive to microclimatic changes (Yolla et al. 2022).

Taxonomic composition

The family Pteridaceae emerged as the richest lineage, with 8 species (25.8% of total species) (Figure 2) and 785 individuals (37.8% of all individuals). Its dominance can be explained by the ecological plasticity of the genus *Adiantum* and related taxa, which are able to colonize semi-shaded slopes, rocky crevices with seepage, and soils with alternating wet-dry cycles (Bowe et al. 2020). Such microhabitats are widespread on Merapi's lower slopes where canopy cover is patchy due to past eruptions and human disturbance. This explains why species like *Adiantum hispidulum* Sw. and *Anogramma leptophylla* (L.) Link thrive, as both are adapted to soils with good drainage but persistent surface moisture. *A. leptophylla* competition via excessive shading, deprivation of soil moisture and nutrients, or smothering of the rootstock may lead to suppression of the sporophyte (Department of Natural Resources and Environment Tasmania 1995).

The Athyriaceae was represented solely by *Deparia petersenii* (Kunze) M.Kato (Figure 3) but contributed (Table 1). This striking monodominance suggests that *Deparia* is highly adapted to moist, semi-open habitats created by Merapi's disturbance regime. Its ability to produce abundant spores and form dense colonies enables it to occupy disturbed ground quickly, which is why it dominated despite the family's low species richness. *D. petersenii* is a prominent fern of the stormwater creek banks (Wilcox 2018).

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Table 1. Pteridophyta species and conservation status

Family	Species	n	Abundance (%)	Habitat	IUCN Status
Athyriaceae	*Deparia petersenii* (Kunze)M.Kato	403	19,40%	T	NE
Cyatheaceae	*Cyathea* sp.	21	1,00%	T	NE
Davalliaceae	*Davallia trichomanoides* Blume	12	0,60%	E	NE
Dryopteridaceae	*Arachniodes aristata* (G.Forst.) Tindale	63	3,00%	T	NE
Dryopteridaceae	*Rumohra adiantiformis* (G.Forst.) Ching	70	3,40%	T	LC
Dryopteridaceae	*Elaphoglossum callifolium* (Blume) J.Sm.	3	0,10%	E	NE
Gleicheniaceae	*Dicranopteris linearis* (Burm.fil.) Underw	58	2,80%	T	LC
Gleicheniaceae	*Sticherus truncatus* (Willd.) Nakai	15	0,70%	T	NE
Lindsaeaceae	*Osmolindsaea odorata* (Roxb.) Lehtonen & Christenah.	62	3,00%	T	NE
Lindsaeaceae	*Odontosoria chinensis* (L.) J.Sm.	30	1,40%	T	NE
Lycopodiaceae	*Lycopodium* sp.	20	1,00%	E	NE
Lygodiaceae	*Lygodium japonicum* (Thunb.) Sw.	15	0,70%	T	NE
Nephrolepidaceae	*Nephrolepis brownii* (Desv.) Hovenkamp & Miyam.	16	0,80%	T	NE
Polypodiaceae	*Goniophlebium percussum* (Cav.) W.H.Wagner & Grether	44	2,10%	E	NE
Polypodiaceae	*Platycerium bifurcatum* (Cav.) C.Chr.	2	0,10%	E	NE
Polypodiaceae	*Pyrrosia longifolia* (Burm.fil.) C.V.Morton	6	0,30%	E	NE
Pteridaceae	*Adiantum capillus-veneris* L.	97	4,70%	T	LC
Pteridaceae	*Adiantum hispidulum* Sw.	216	10,40%	T	NE
Pteridaceae	*Adiantum raddianum* C.Presl	135	6,50%	T	NE
Pteridaceae	*Anogramma leptophylla* (L.) Link	194	9,30%	T	LC
Pteridaceae	*Pityrogramma chrysophylla* (Sw.) Link	31	1,50%	T	NE
Pteridaceae	*Pityrogramma calomelanos* (L.) Link	47	2,30%	T	NE
Pteridaceae	*Pteris ensiformis* Burm.	23	1,10%	T	NE
Pteridaceae	*Pteris vittata* L.	42	2,00%	T	LC
Selaginellaceae	*Selaginella willdenowii (Desv.) Baker*	8	0,40%	L	NE
Selaginellaceae	*Selaginella kraussiana (Kunze) A.Braun*	11	0,50%	L	NE
Tectariaceae	*Tectaria dissecta* (G.Forst.) Lellinger	30	1,40%	T	NE
Tectariaceae	*Tectaria decurrens* (C.Presl) Copel.	20	1%	L	NE
Thelypteridaceae	*Christella parasitica* (L.) H.Lév.	9	0,40%	T	NE
Thelypteridaceae	*Christella subpubescens* (Blume) Holttum	311	15%	T	NE
Thelypteridaceae	*Chingia ferox* (Blume) Holttum	61	2,90%	T	NE

Note: n: number of individu, E: epifit, L: litofit, T: terestrial, LC: Least Concern, NE: Not Evaluated

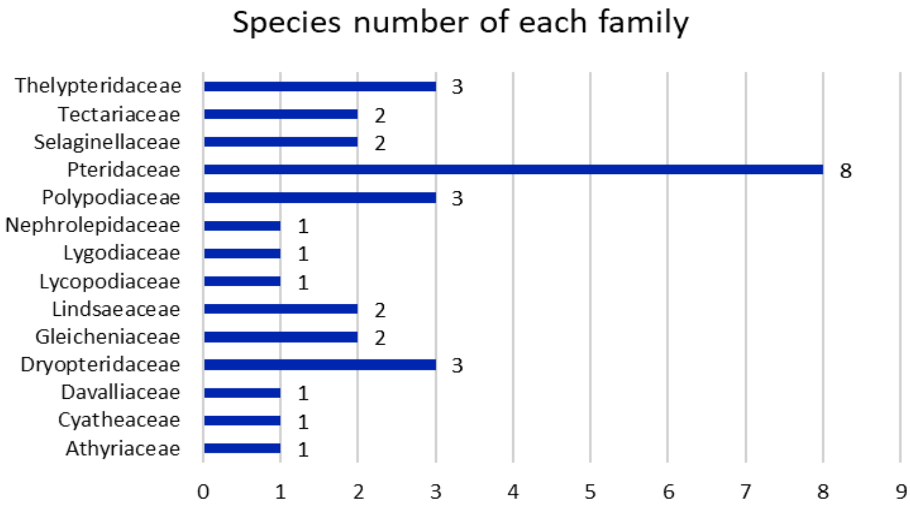

Figure 2 . Family diagram of Pteridophytes finding on research


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Figure 3. 1. *Deparia petersenii* (Kunze)M.Kato; 2. *Cyathea* sp.; 3. *Davallia trichomanoides* Blume; 4. *Arachniodes aristata* (G.Forst.) Tindale; 5. *Rumohra adiantiformis* (G.Forst.) Ching; 6. *Elaphoglossum callifolium* (Blume) J.Sm.; 7. *Dicranopteris linearis* (Burm.fil.) Underw; 8. *Sticherus truncatus* (Willd.) Nakai; 9. *Osmolindsaea odorata* (Roxb.) Lehtonen & Christenah..; 10. *Odontosoria chinensis* (L.) J.Sm.; 11. *Lycopodium* sp.; 12. *Lygodium japonicum* (Thunb.) Sw.; 13. *Nephrolepis brownii* (Desv.) Hovenkamp & Miyam.; 14. *Goniophlebium percussum* (Cav.) W.H.Wagner & Grether; 15. *Platycerium bifurcatum* (Cav.) C.Chr.; 16. *Pyrrosia longifolia* (Burm.fil.) C.V.Morton; 17. *Adiantum capillus-veneris* L.; 18. *Adiantum hispidulum* Sw.; 19. *Adiantum raddianum* C.Presl; 20. *Anogramma leptophylla* (L.) Link; 21. *Pityrogramma chrysophylla* (Sw.) Link; 22. *Pityrogramma calomelanos* (L.) Link; 23. *Pteris ensiformis* Burm.; 24. *Pteris vittata* L.; 25. *Selaginella willdenowii* (Desv.) Baker; 26. *Selaginella kraussiana* (Kunze) A.Braun; 27. *Tectaria dissecta* (G.Forst.) Lellinger; 28. *Tectaria decurrens* (C.Presl) Copel.; 29. *Christella parasitica* (L.) H.Lév.; 30. *Christella subpubescens* (Blume) Holttum; 31. *Chingia ferox* (Blume) Holttum;

The Thelypteridaceae was represented by only three species but reached 381 individuals (18.3%) (Table 1), largely due to *Christella subpubescens* (Blume) Holttum (Table 1, Figure 3). This species' success reflects its ability to tolerate semi-disturbed forest floors, where moderate light and consistent soil moisture prevail. The abundance of Thelypteridaceae indicates that the sites contain recovering secondary habitats, where such disturbance-tolerant ferns are favored.

By contrast, families such as Dryopteridaceae (3 species; 136 individuals, 6.6%) and Lindsaeaceae (2 species; 92 individuals, 4.4%) had moderate representation. Both families prefer shaded, humid microsites, which are more limited in the semi-open Merapi slopes, explaining their lower abundance. Minor families including Polypodiaceae (3 species; 52 individuals, 2.5%) and Selaginellaceae (2 species; 19 individuals, 0.9%) were restricted by substrate availability. Polypodiaceae are largely epiphytic, thus limited by the availability of large host trees, while Selaginellaceae depend on moist rocky surfaces, which occur in patches along stream banks and cliff faces (Valdespino 2016). Families represented by a single species with very low abundance such as Davalliaceae (*Davallia trichomanoides* Blume, 12 individuals) highlight taxa with narrow ecological niches that are not widely available in the surveyed areas (Table 1, Figure 2).

Dominant and rare species

The most dominant species were *D. petersenii* (403 individuals, 19.4%), *Christella subpubescens* (311 individuals, 15.0%), *A. hispidulum* (216, 10.4%), and *A. leptophylla* (194 individuals, 9.3%) (Table 1, Figure 3). Together, these four species accounted for more than 54% of all individuals. Their ecological success can be explained by traits such as high fecundity, tolerance to light fluctuations, and efficient colonization of moist, disturbed soils. For example, *D. petersenii* often dominates where soil is periodically disturbed but remains moist, while *C. subpubescens* is known as a rapid colonizer of secondary habitats. Moseley and Proctor (2016) stated *Adiantum* species exploit seepage slopes and rock surfaces, where constant humidity supports continuous recruitment.

In contrast, several species were rare, including *P. bifurcatum* (2 individuals) and *Elaphoglossum callifolium* (Blume) J.Sm. (3 individuals). Their rarity is linked to strict habitat specialization. *Platycerium* is an epiphyte requiring mature host trees with rough bark and stable canopy microclimates, which are limited in the study sites. *Elaphoglossum* prefers persistently shaded, moist forest interiors, which are fragmented in the semi-open environments of Merapi. This explains why these taxa persist in very low numbers compared to generalist species.

Habitat distribution

Various types of ferns can be found in several environments that are suitable for fern habitat. Ferns can also live in tropical and subtropical forests, on beaches (sea ferns) and on mountain slopes, and some even live around craters. Ferns cannot live in snowy and dry areas. According to Ulfa et al. (2023) that ferns can live in damp places, on the ground (terrestrial), on other plants (epiphytes), and in water ferns (hygrophytes). Apart from that, ferns can also grow on rocks (lithophytes). Generally, ferns live in humid places and grow more in mountainous areas than in the lowlands. This is because high humidity, large amounts of water flow, fog and the intensity of rainfall can affect the type.

Terrestrial species

The majority of ferns in the study area were terrestrial, represented by 22 species (70.9% of all species) and 1,949 individuals (93.9% of total abundance) (Table 1, Figure 4). This overwhelming dominance indicates that forest floor habitats with moist volcanic soils provide the most suitable conditions for fern growth on the southeastern slope of Mount Merapi. Species such as *D. petersenii* (403 individuals), *C. subpubescens* (311 individuals), *A. hispidulum* (216 individuals), and *Anogramma leptophylla* (194 individuals) illustrate the success of terrestrial ferns, together accounting for nearly half of all individuals.

This pattern can be explained by abiotic conditions where volcanic soils at Merapi are porous yet moisture-retentive, enriched by mineral deposits, and buffered by neutral pH (6.9-7.4), which favors root development and nutrient absorption (Saputro and Utami 2020). In addition, the montane climate provides moderate temperatures (20-24°C) and high relative humidity (69-76%), both essential for maintaining gametophyte viability and successful fertilization (Yolla et al. 2022). The high proportion of terrestrial species aligns with studies from other Indonesian montane forests, where forest floor ferns dominate due to stable moisture and shaded microsites (Astuti et al. 2017; Priambudi et al. 2022).

Epiphytic species

A smaller proportion of the flora was epiphytic, consisting of 6 species (19.3%) (Table 1, Figure 4). with a total of 87 individuals (4.2%). Examples include *D. trichomanoides* (12 individuals), *E. callifolium* (3 individuals), and *P. bifurcatum* (2 individuals). The low abundance of epiphytes reflects limited availability of large host trees in the survey area, as much of the vegetation consists of secondary growth with relatively small diameter trees. Epiphytic ferns depend on stable canopy microclimates with consistent shade, bark moisture, and organic debris accumulation to support their roots and rhizomes (Karim et al. 2022).

The rarity of epiphytes such as *P. bifurcatum* highlights their vulnerability in disturbed or secondary forests. With only 2 individuals recorded, its persistence depends on the presence of large canopy trees with rough bark, which were scarce in the study transects. Similarly, *E. callifolium* (3 individuals) is adapted to persistently humid, shaded interiors that are fragmented due to canopy gaps and disturbance.

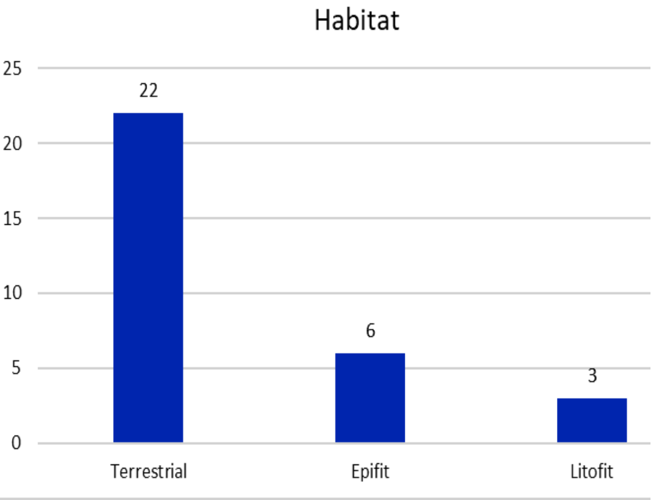

Figure 4. Pteridophyta habitat found by each species in the ecosystem

Lithophytic species

Only 3 species (9.7%) were lithophytic, totaling 39 individuals (1.9%) (Table 1, Figure 4). These included *S. willdenowii* (8 individuals), *S. kraussiana* (11 individuals), and *T. decurrens* (20 individuals). Lithophytic ferns are constrained by the limited extent of moist rocky substrates in the surveyed areas. Volcanic slopes of Merapi provide rocky surfaces, but many are too dry or unstable due to erosion. The few species that do persist have specialized adaptations, such as drought tolerance in *Selaginella* and efficient water absorption on shaded rocks (Nowak et al. 2022). The scarcity of lithophytes suggests that while volcanic slopes provide rocky habitats, only niches with consistent seepage or moss cover can sustain fern growth. This explains the low abundance compared to terrestrial species.

The habitat distribution clearly demonstrates that terrestrial environments dominate fern diversity and abundance in Merapi's southeastern slope. Epiphytic and lithophytic ferns are present but limited by host-tree availability, canopy structure, and rocky microhabitats. This imbalance reflects the influence of abiotic factors (soil moisture, pH, temperature, and microclimatic stability) in shaping community structure. In ecosystems where volcanic disturbance and secondary succession are frequent, terrestrial ferns adapt best, while epiphytes and lithophytes remain confined to microhabitat refugia.

Environmental factors

The ecosystem in this area is still well maintained even though it is surrounded by villages. Sapuangin's location close to Mount Merapi means that the area has fertile agricultural land, which is planted with many food crops, fruit plants and plantation crops (Widhiastuti et al. 2023). The types of food crops that are widely grown are corn, cassava, sweet potatoes, coffee, chilies and intercropping. Apart from plants for consumption, many ferns also grow in the area. The vegetation found in the Kalireno area consists of trees and ferns. Pteridophytes can be used as indicators of forest integrity. If there are lots of ferns in the environment, then the environment is said to be good for supporting the life of an organism and the environment has not been polluted by pollutants, and vice versa (Ningsih 2021).

Elevation and soil temperature

The average elevation of the study sites was 1,213.5 masl, with a mean soil temperature of 22.29°C (Table 2). These conditions are considered optimum for tropical and subtropical ferns, which generally thrive between 20-25°C at mid-elevations (Firoozi et al. 2025). Species richness peaked under this range namely *D. petersenii* and *C. subpubescens* were abundant, reflecting their adaptation to montane slopes with moderate warmth and sufficient shade. By contrast, species such as *O. regalis* and *E. callifolium* were rare, possibly because these taxa are more competitive in cooler, shaded habitats at higher elevations or in valley bottoms. The prevailing temperature at Merapi is thus optimal for generalist terrestrial ferns but only marginal for taxa specialized to cooler or denser forest interiors.

Table 2. Research abiotic factors

Abiotic factors	Average score
Soil moisture (%)	72,5
Soil pH	7,15
Soil temperature (°C)	22,29
High (masl)	1213,5

Soil moisture

Average soil moisture was 72.5% (Table 2)., a level regarded as high and favorable for fern reproduction. Since fern fertilization requires free water for sperm motility, moisture above 70% supports both gametophyte viability and sporophyte establishment (Yolla et al. 2022). Terrestrial dominants such as *A. hispidulum* and *A. leptophylla* were concentrated in moist seepage areas and drainage slopes, illustrating how continuous water availability sustains population growth.

However, species with lower abundance like *S. ornata* were restricted to shaded rocky surfaces with localized high humidity. This shows that while the general soil moisture regime is ideal for most terrestrial species, lithophytes and epiphytes rely on microhabitats where humidity is maintained year-round.

Soil pH

The soil pH in the study area averaged 7.15, falling within the neutral range, which is generally favorable for nutrient uptake and fern growth (Saputro and Utami 2020). Neutral soils, such as those in Merapi, facilitate the solubility of key nutrients, including nitrogen and phosphorus, which are essential for sporophyte development and growth. This is why many of the dominant species, such as *A. raddianum* (135 individuals) thrived in this environment. The neutral pH enhances the availability of these nutrients, allowing for higher growth rates and supporting the abundant, generalist fern taxa in the community.

In contrast, species like *E. callifolium* (3 individuals) are rare, but not because they require acidic soils. While *E. callifolium* is adapted to high-humidity, shaded environments, its rarity in Merapi is likely due to its specific microhabitat requirements, such as a stable, humid understorey and persistent shade, which are less common in the secondary forests of the region. This suggests that the neutral soils at Merapi are suitable for a wide variety of ferns, but species with more specific habitat needs, including those requiring stable moisture or deeper shade, may be underrepresented in disturbed montane forests.

The fern assemblage on Merapi's southeastern slope demonstrates how abiotic conditions collectively shape community structure (i) optimal soil temperature (22.29°C) and neutral pH (7.15) enabled the proliferation of generalist terrestrial ferns such as *D. petersenii* and *C. subpubescens*. These taxa exploit forest-floor niches with consistent warmth and fertility, forming dense populations; (ii) high soil moisture (72.5%) supported the persistence of water-demanding taxa like *A. hispidulum* and *A. leptophylla*, which dominate seepage slopes and banks where constant humidity maintains gametophyte activity; (iii) elevation at ~1,200 masl provided intermediate climatic conditions that support diverse families, but at the same time constrained cold-adapted or shade-dependent taxa such as *O. regalis* and *E. callifolium*; (iv) habitat specialists (e.g., *P. bifurcatum*) were restricted by the scarcity of large host trees needed for epiphytic establishment, reflecting the limitation of structural rather than chemical or climatic factors.

Overall, the prevailing abiotic conditions can be regarded as ideal for the majority of terrestrial ferns, particularly Pteridaceae, Athyriaceae, and Thelypteridaceae, which together contributed over 75% of all individuals. Conversely, species requiring cooler, more acidic, or structurally stable microhabitats remain rare, highlighting the dependence of fern diversity on both broad-scale soil-climate factors and fine-scale habitat heterogeneity.

Species abundance patterns

Dominant species

Deparia petersenii (403 individuals; 19.4%) was the leading the most abundance species. Its dominance can be attributed to its clonal spread and prolific spore production, which allow it to rapidly colonize moist disturbed soils that are abundant in the volcanic terrain. The prevailing conditions of soil moisture of 72.5%, neutral pH of 7.15, and average soil temperature of 22.29 °C are close to optimum for its reproductive cycle, providing an ideal environment for continuous recruitment. Another key species, *C. subpubescens* thrived in semi-open forest floors with stable humidity. Its ability to tolerate canopy gaps and spread vegetatively across moist soils explains its high abundance in secondary habitats. Pteridaceae members such as *A. hispidulum*, *A. leptophylla*, *A. raddianum* and *A. capillus-veneris* were also highly represented. Gu et al. (2024) stated Pteridaceae species have a cosmopolitan distribution concentrated in wet tropical and arid regions, occupying various ecosystems such as terrestrial, epiphytic, rupestral, and even aquatic. Their success is linked to their preference for seepage slopes, rocky banks, and moist soils with neutral pH, conditions that are well represented on Merapi’s slopes. Other moderately abundant taxa, including *A. aristata* and *C. ferox* benefitted from the humid soils but were less dominant due to slower growth and preference for deeper shade, which is less available in semi-open secondary forests.

Rare species

Elaphoglossum callifolium was confined to shaded microsites and is typically associated with cooler, more acidic forest soils. In Merapi, the neutral soil pH of 7.15 and semi-open canopy conditions likely limited its establishment, making the habitat only marginally suitable. Its inherently slow growth and lower spore output further reduce its competitive ability against fast-colonizing dominants. *P. bifurcatum*, an epiphyte, was also rare due to the scarcity of large host trees with rough bark and canopy microclimates capable of retaining constant humidity. Although the general soil conditions were favorable, the absence of suitable structural habitats in secondary stands restricted its abundance. These examples demonstrate that rare species are constrained not by the general soil-climate regime but by highly specific microhabitat requirements that were underrepresented in the surveyed areas.

The overall abundance structure reflects a community dominated by generalist terrestrial ferns that are well adapted to the prevailing abiotic conditions, while specialist species persist in marginal niches. High soil moisture (72.5%) and moderate temperature (22.29 °C) were optimal for dominant taxa such as *D. petersenii*, *C. subpubescens*, and *A. hispidulum*, which rapidly colonize disturbed ground and stabilize community composition. Neutral soil pH (7.15) favored nutrient availability and benefited families such as Pteridaceae and Thelypteridaceae, explaining their large population shares, whereas acidophilic species like *E. callifolium* remained rare. Mid-elevation conditions at 1,213.5 masl provided an intermediate climate that sustained high overall richness, but were less suitable for taxa specialized in cooler, shaded habitats or dependent on mature canopy structures. The scarcity of *P. bifurcatum* illustrates how structural limitations, rather than climatic ones, can constrain epiphytic abundance. Collectively, these patterns indicate that the fern community is stabilized by abundant colonizers that exploit optimum soil and climate conditions, while rare specialists highlight the importance of microhabitat heterogeneity and forest structural integrity in maintaining ecological uniqueness.

Biodiversity indices

The diversity indices used in this research encompass three species diversity indicators, namely the Shannon-Wiener index (H’), Species Evenness index (E), and Margalef's Species Richness index (Dmg) (Table 3). Species diversity indices can be utilized to express the community structure in a research area (Indriyanto 2006). The indices employed are also in line with those used by Kunakh et al. (2023), who elucidated that the Shannon-Wiener index, evenness index, and Margalef's species richness index are the most suitable indices among traditional ones.

Shannon-Wiener index (H')

The Shannon-Wiener index of the fern assemblage was H′ = 2.77 (Table 3), which falls into the moderate category. This result indicates that while the community has considerable diversity, it is not highly balanced because certain species exert strong dominance.

Table 3. Biodiversity indicator of pteridophytes species Shannon-Wiener diversity index (H'), Evenness index (E), Margalef species richness index (Dmg)

Biodiversity index	Index number	Category
H'	2,77	Moderate
Dmg	3,93	Moderate
E	0,81	High

Note: H’ = Shannon-Wiener diversity index (H'); E = Evenness index; Dmg = Margalef species richness index

The large populations of *D. petersenii* and *C. subpubescens* substantially lowered the index, as their dominance reduced the contribution of rarer taxa. Nevertheless, the presence of many intermediate-abundance species, such as *A. hispidulum*, *A. leptophylla*, and *A. raddianum* prevented the index from declining further. Ecologically, the moderate H′ value is a direct outcome of the disturbance-driven environment of Mount Merapi, where volcanic activity and secondary succession promote colonization by generalist species that dominate numerically while still allowing coexistence of less abundant taxa (Astuti et al. 2017; Priambudi et al. 2022). The prevailing abiotic conditions moist soils (72.5%), neutral pH (7.15), and moderate temperature (22.29°C) are near-optimal for many terrestrial ferns, which explains why colonizers proliferated and shaped the overall diversity value.

Margalef richness index (Dmg)

The Margalef richness index was Dmg = 3.93 (Table 3), also within the moderate category. With 31 species across 15 families and 2,075 individuals, richness is significant but not exceptionally high. This value reflects the tension between richness and dominance: while the species list is relatively long, a few taxa contributed disproportionately to abundance, limiting the effective contribution of the remaining species. Habitat generalists such as *D. petersenii* and *C. subpubescens* occupy large niches under the neutral soil pH and high moisture, leaving fewer opportunities for specialists such as *P. bifurcatum* and *E. callifolium*. Thus, richness is moderated by the availability of microhabitats, which are reduced in semi-open secondary forests compared to primary forests. The moderate Dmg value also reflects the volcanic setting: while disturbance promotes colonizer diversity, recurrent canopy gaps and soil instability constrain the persistence of niche-specific species. Therefore, the index value is not low, because richness is maintained by 31 species, but it is not high either, because the ecological space is largely occupied by a limited set of successful colonizers.

Evenness index (E)

The Pielou's evenness index was E = 0.81 (Table 3),, which is considered high evenness. This means that aside from the few numerically dominant species, many other taxa were represented at similar intermediate abundances. Species such as *A. aristata* and *C. ferox* exemplify this pattern that none were overwhelmingly dominant, but each maintained a stable presence in the community. The relatively balanced distribution among these taxa raised the evenness index despite the strong presence of *Deparia* and *Christella*. This outcome is closely tied to the heterogeneous microhabitats of Merapi's slopes, where varying light intensities, seepage lines, and soil depths create niches for multiple species. High evenness underlines that competitive exclusion has not eliminated less dominant ferns, and that the community supports stable coexistence across niches despite moderate diversity and richness values (Yolla et al. 2022; Ramndana et al. 2023).

The indices reveal a moderately diverse but highly balanced fern community. The moderate H′ and Dmg values arise from the strong influence of disturbance-tolerant colonizers (*D. petersenii*, *C. subpubescens*, *A. hispidulum*), which flourish under moist, neutral, and moderately warm soils at mid-elevation (1,213.5 masl). These generalists dominate the community numerically, thereby reducing effective diversity and richness. At the same time, the high evenness (E = 0.81) demonstrates that many taxa with intermediate abundances coexist successfully, supported by the heterogeneous volcanic landscape that provides diverse microhabitats. Thus, the fern community is stabilized by abundant colonizers that secure biomass and ecosystem functioning, while rare specialists contribute ecological uniqueness. This duality reflects the resilience of montane volcanic systems, where both disturbance-driven generalists and habitat-dependent specialists coexist to maintain biodiversity integrity.

Conservation status and implications

One way to protect is by knowing the conservation status of fern species. Conservation status is a status given by the IUCN Red List to a type of plant which is used as an initial effort to prevent the extinction of each type of plant, so that protection can be immediately sought.

Species with Least Concern (LC) status

Only a few species recorded in the study were listed as Least Concern (LC) in the IUCN Red List (Table 4) Globally, *Dicranopteris linearis* is categorized as LC because it is a highly resilient colonizer, distributed widely across Asia and thriving in open, disturbed soils. Its fast-growing rhizomes and ability to establish dense thickets make it resistant to habitat disturbance and thus secure on a global scale. Locally at Merapi, this status is reinforced by its adaptability to volcanic slopes with semi-open canopy and neutral soils, conditions that mirror its global ecological niche.

Similarly, *O. regalis* is globally LC because of its broad geographical distribution in temperate and tropical montane zones. Its adaptability to fertile, moist soils explains its stable global population. However, at Merapi, its abundance was low (9 individuals), suggesting that while globally secure, its local population is constrained by the limited extent of permanently moist habitats in semi-open secondary forests. This contrast emphasizes that global security does not always guarantee local abundance, especially in disturbed volcanic systems.

Species not evaluated (NE)

Most species in the assemblage, including highly abundant taxa such as *D. petersenii*, *C. subpubescens*, and *A. hispidulum*, have not yet been formally assessed by IUCN and are thus categorized as Not Evaluated (NE). The absence of global assessment may reflect the taxonomic and ecological bias in Red List evaluations, where ferns are often underrepresented compared to flowering plants.

Table 4. Conservation status as Least Concern of recorded Pteridophyte species by IUCN

Family	Species	Abundance (individuals; %)	IUCN	Global reason	Local reason
Gleicheniaceae	*D. linearis*	58; 2.8%	LC	Known as pioneer fern, globally secure due to rapid rhizome spread.	Locally common on open disturbed volcanic soils, reflecting its colonizer strategy.
Osmundaceae	*R. adiantiformis*	70; 3.4%	LC	The species is a habitat generalist with robust, creeping rhizomes and abundant spore production, allowing rapid recovery after disturbance (e.g., canopy gaps, edge effects)	Stable local presence under suitable abiotic conditions. At the study site, placing it among the moderately abundant taxa.
Pteridaceae	*A. capillus-veneris*	97; 4.7%	LC	Widespread across temperate and tropical regions, tolerant of diverse substrates.	Locally stable in seepage slopes with neutral pH (7.15) and high moisture (72.5%).
Pteridaceae	*A. leptophylla*	194; 9.3%	LC	Global colonizer with annual life cycle, resilient to seasonal change.	Locally abundant in moist rocky banks; thrives under 22.29 °C temperature.
Pteridaceae	*P. vittata*	42; 2%	LC	Globally secure, widely used in phytoremediation due to arsenic tolerance.	Locally present but not dominant; survives in rocky slopes with moderate light.

Globally, these species may appear common in their ranges, but without official evaluation, their long-term trends remain uncertain. Locally, the NE category creates challenges for conservation planning. For instance, although *D. petersenii* and *C. subpubescens* are abundant in Merapi due to their disturbance-tolerant strategies and compatibility with moist, neutral soils, their regional populations could still be vulnerable to habitat fragmentation or climate change. Meanwhile, rare taxa such as *P. bifurcatum* and *E. callifolium* are also NE. Globally, *P. bifurcatum* is often cultivated as an ornamental species, which may obscure its wild population dynamics. Locally, however, its scarcity highlights the lack of mature host trees in secondary forests. *E. callifolium*, on the other hand, requires deep shade and consistently moist microsites, conditions that are fragmented at Merapi, explaining its rarity. These cases show how the NE status underrepresents the potential vulnerability of habitat specialists at local scales.

The mixture of LC and NE statuses has important implications. LC species such as *D. linearis* confirm the resilience of generalist colonizers, which maintain stable populations both globally and locally. However, the dominance of NE species reflects a major knowledge gap. While abundant species such as *D. petersenii* seem secure in Merapi, their long-term conservation outlook is unknown without global assessments. Conversely, rare specialists like *P. bifurcatum* and *E. callifolium* demonstrate that local rarity can persist even if species appear stable or overlooked at global scales.

This emphasizes the need for dual-scale conservation perspectives (i) globally, increasing the representation of ferns in the IUCN Red List is essential to capture their true conservation needs; (ii) locally, habitat management in Merapi should prioritize maintaining moist microhabitats and mature canopy structures that support rare taxa, while also monitoring abundant colonizers for potential shifts under climate and land-use changes.

In conclusion this study recorded 31 species of Pteridophytes belonging to 14 families and 2,075 individuals on the southeastern slope of Mount Merapi National Park, with Pteridaceae as the most diverse and abundant family, while *D. petersenii* and *C. subpubescens* were the dominant species and *P. bifurcatum* and *E. callifolium* the rarest. Most species were terrestrial (22 species; 93.9% of individuals), reflecting the suitability of volcanic soils characterized by high moisture (72.5%), neutral pH (7.15), moderate soil temperature (22.29°C), and mid-elevation (1,213.5 masl) for fern growth. The Shannon index (H′ = 2.77) and Margalef index (Dmg = 3.93) indicated moderate diversity and richness, while the evenness index (E = 0.81) reflected balanced coexistence despite the dominance of generalists. Conservation analysis showed that only five species were categorized as Least Concern (LC), while the majority were Not Evaluated (NE), underscoring both the ecological resilience of generalists and the vulnerability of specialists that depend on scarce microhabitats. Overall, the findings highlight that fern communities in Mount Merapi are structured by a few abundant colonizers but sustained by diverse coexisting taxa, and that conservation efforts should focus on protecting habitat heterogeneity to support both dominant and rare species.

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