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Diversity of Pteridophytes Along Riverbanks in Tiganderket District, Karo Regency, North Sumatra, Indonesia

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ABSTRACT

Terrestrial ecosystems along former cold-lava flow paths in Tiganderket District, Karo Regency, play a vital ecological role in post-eruption recovery. Pteridophytes are recognized as key pioneer components in the ecological succession of terrestrial vegetation. However, previous studies have generally focused on species inventories and have not evaluated the spatial dynamics of Pteridophyte communities or their specific responses to microclimatic factors in cold-lava-affected areas. This study addresses this gap by analyzing Pteridophyte diversity along the spatial gradient of former cold-lava flow paths (upstream, midstream, and downstream) and quantifying correlations with environmental factors. Data collection employed the transect method, followed by analyses of diversity (Shannon-Wiener index), dominance (Simpson index), and *Principal Component Analysis* (PCA). The study identified 16 species across 7 families, revealing moderate diversity (H' = 2.16–2.36) and low dominance (C = 0.11–0.14). PCA analysis yielded new insights, showing that community structure in the area is positively influenced by specific ambient temperatures within the 26°C–34°C range. In conclusion, the Pteridophyte community structure in the area is relatively stable. These findings provide new insights indicating that the post-eruption ecological succession process, particularly along cold-lava flow paths, is proceeding effectively and in a balanced manner.

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INTRODUCTION

Pteridophytes play a crucial ecological role by stabilizing soil structure, providing biomass, and serving as indicators of environmental change. Of the approximately 10,000 pteridophyte species worldwide, more than 1,300 are found in Indonesia; however, efforts to document and conserve them lag behind those for flowering plants (Retnowati & Rugayah, 2019). One region with a wealth of germplasm that remains underexplored is Tiganderket District in Karo Regency. This humid highland area offers an ideal microclimate for fern growth (Djuita & Ermayanti, 2018), yet local utilization of this potential has thus far been limited to food sources *(Diplazium esculentum)* and ornamental plants *(Asplenium nidus)*. Beyond its potential biodiversity, the river ecosystem in Tiganderket District requires urgent study due to severe damage caused by volcanic material and cold lava flows following the 2016 eruption of Mount Sinabung.

The disaster destroyed riparian vegetation along the riverbanks and buried the area under thick volcanic deposits for approximately five years. Currently, the ecosystem is showing signs of recovery (primary ecological succession), with Pteridophytes consistently acting as pioneer species. Ecologically, the success of Pteridophytes as early colonizers in ecosystems with disturbed volcanic soil is greatly supported by their symbiotic interactions with soil microbiomes, which facilitate nutrient fixation and promote plant growth in extreme environments (Swain et al., 2025). The success of ferns in colonizing nutrient poor volcanic substrates is aided by spore reproduction mechanisms producing spores that are extremely light and easily dispersed by wind as well as the physiological adaptability of their gametophytes to extreme microclimatic conditions and marginal substrates (Page, 2002). The presence of Pteridophyte communities during this early stage of succession facilitates the weathering of cold lava substrates, enhances organic matter accumulation, and retains soil moisture, ultimately paving the way for a more stable microclimate conducive to the colonization of higher plants (Suissa & Sundue, 2020).

Given that cold lava flows create a gradient of disturbance levels extending from the eruption source to downstream areas, ecosystem recovery dynamics will vary at each location. Consequently, analyzing Pteridophyte diversity and community structure along this spatial transect (upstream, midstream, and downstream) serves not merely as a taxonomic inventory but as a crucial ecological proxy. Variations in diversity and dominance indices across these sites can reflect the stages and trajectories of ongoing ecological succession. By surveying fern diversity along the margins of these former cold lava flows, we can spatially map species distribution and quantitatively assess indicators of successful ecological recovery.

Furthermore, the rich biodiversity and successional dynamics of Pteridophytes in this region offer significant potential as a source for authentic biology learning, particularly regarding the morphology, adaptation, and evolution of land plants. Ironically, biology instruction in local schools has not fully leveraged this potential, as it remains dominated by lecture-based methods and teaching aids that lack contextual relevance (Susanto & Hidayat, 2016). This gap renders ecology education largely theoretical, offering insufficient real-world experience in addressing complex environmental issues. Integrating local ecosystems into biology instruction has proven effective within the framework of Contextual Teaching and Learning (CTL), where the environment serves as a "living laboratory" (Yaya et al., 2025). Direct engagement with local ecosystems not only enhances students' conceptual and critical understanding of ecological subject matter but also fosters a holistic awareness of environmental conservation (Yaya et al., 2025). To address the gap regarding post-disaster ecology and the underutilization of the local environment in education, this study aims to inventory Pteridophyte diversity along the river in Tiganderket District and transform these findings into innovative, relevant biology learning materials that incorporate local conservation perspectives.

MATERIALS AND METHOD

The study was conducted in January 2026 along the riverbanks affected by cold lava flows from the Mount Sinabung eruption, located in Tiganderket District, Karo Regency. The study used a GPS device, thermometer, lux meter, pH meter, hygrometer, camera, plastic bags, pruning shears, label paper, and writing instruments.

This study employed an exploratory method to survey the presence of Pteridophytes at three specific locations along the riverbank. It utilized a descriptive research design with a quantitative approach. Sampling was conducted along designated study paths using purposive sampling. Transects following the riverbank were used; each location comprised two transect lines-one on the right bank and one on the left-spanning a total river habitat length of 5,700 meters in Tiganderket District. The river stretch was divided into three observation points: Location 1 (upstream), Location 2 (midstream), and Location 3 (downstream). Data collection was carried out through direct field surveys along the river at these three locations. At each location, the survey covered a 500-meter transect path. During the survey, Pteridophyte samples were recorded on both sides of the river within a 10-meter zone extending inland from the bank. This 10-meter range focused on observing both terrestrial and epiphytic Pteridophytes growing on soil, rocks, cliffs, and riverside tree trunks.

Pteridophytes were identified based on their morphological characteristics, including leaves, roots, stems, and spores. Identification was performed using the iNaturalist application and relevant scientific journals. This study employs a quantitative data analysis method in which the diversity index and dominance index are calculated for all encountered pteridophyte samples, and a correlation analysis is conducted between environmental factors and the pteridophytes at each observation site.

1. Diversity Index

   The diversity index is determined using the Shannon-Wiener formula (Shannon & Wiener, 1988, as cited in Yolla et al., 2022):

   $H' = -\sum Pi \ In \ Pi$

   Legend:

   H': Species diversity index

   Pi: ni/N

   ni: Number of individuals of species i

   N: Total number of individuals

   Subsequently, the level of species diversity is determined and classified into three categories:

   $H' > 3$ = High

   $1 \leq H' \leq 3$ = Moderate

   $H' < 1$ = Low

2. Dominance Index

   The dominance index is determined using Simpson's dominance formula (Khamalia, 2018).

   $D = 1 - \sum Pi^2$

   Legend:

   D: Simpson's dominance index

   Pi: ni/N

   ni: Number of individuals of each species

   N: Total number of individuals of all species

3. Environmental Factor Correlation

   The analysis of the relationship between environmental factors and pteridophyte diversity aims to measure the association between the measured environmental variables (temperature, air humidity, light intensity, soil pH) and the level of pteridophyte diversity at each observation site. Principal Component Analysis (PCA) is used to analyze these parameters.

RESULTS AND DISCUSSION

1. Diversity Index

   Based on the calculations performed for all species at each location, the diversity index values (H') were obtained, as shown in the following figure.

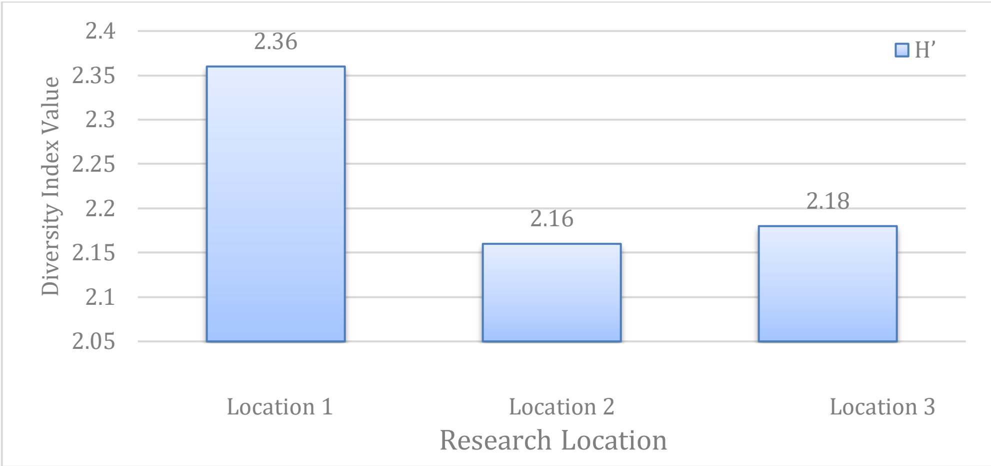

Figure 1. Diversity Index (H’) of Pteridophytes

Based on the Shannon-Wiener diversity index (H') calculations, all study sites exhibited a moderate level of diversity, with H' values ranging from 2.16 to 2.36. These values indicate that the Pteridophyte plant communities at the three sites are relatively stable, characterized by a fairly even distribution of individuals across species, thereby avoiding excessive dominance by any single species. Overall, the variation in diversity index values is influenced by diverse habitats comprising sandy substrates, rocky areas, soil, and trees, which create conditions conducive to the growth and distribution of Pteridophytes, thus maintaining a moderate level of diversity across all study sites.

Based on the research data, 16 species of Pteridophytes were identified across three observation sites representing various habitat types. The most abundant Pteridophyte species across all study sites was *Nephrolepis hirsutula* (427 individuals), while the least abundant was *Pteris vittata* (24 individuals). The data regarding the Pteridophyte species found are presented below:

Table 1. Types of Pteridophytes found at the research site

No.	Classification	Habitat	Image	L.1	L.2	L.3	Total
1.	Kingdom : Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : ptrideceae Genus : *Pityrogramma* Spesies : *Pityrogramma calomelanos* (L.)	Moist Soil		56	-	83	139
2.	Kingdom: Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : ptrideceae Genus. : *Pteris* Spesies : *Pteris ensiformis*	Rocky Ground		-	-	43	43

3.	Kingdom : Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : pterideceae Genus : *Pteris* Spesies : *Pteris vittata*	Moist Soil		24	-	-	24
4.	Kingdom : Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : pterideceae Genus : *Phymatosorus* Spesies : *Phymatosorus scolopendria*	Epiphyte on a Tree		-	29	14	43
5.	Kingdom : Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : Nephrolepidaceae Genus : *Nephrolepis* Spesies : *Nephrolepis brownii*	Moist Soil		92	64	83	239
6.	Kingdom : Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : Nephropidaceae Genus : *Nephrolepis* Spesies : *Nephrolepis hirsutula*	Moist Soil		131	139	157	427
7.	Kingdom : Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : Nephrolepidaceae Genus : *Nephrolepis* Spesies : *Nephrolepis abrupta*	Rocky Ground		37	39	52	128
8.	Kingdom : Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : Thelypteridaceae Genus :*Christella* Spesies :*Chistella parasitaca*.	Swamps		48	-	-	48

9.	Kingdom : Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : Thelypteridaceae Genus :*Christella* Spesies :*Christella leveille*	Epiphyte On Rocks		16	32	58	106
10.	Kingdom : Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : Thelypteridaceae Genus : *Cyclosorus* Spesies :*Cyclosorus interruptus*	Swamps		37	-	51	88
11.	Kingdom: Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : Thelypteridaceae Genus: *Macrothelypteris* Spesies :*Macrothelypteris torresiana*	Moist Soil		13	27	-	40
12.	Kingdom: Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo : Polypodiales Famili : Thelypteridaceae Genus: *Amblovenatum* Spesies: *Amblovenatum opulentum*	Moist Soil		32	9	-	41
13.	Kingdom: Plantae Divisi: Pteridophyta Kelas: Polypodopsida Ordo : Polypodiales Famili : Aspleniaceae Genus: *Asplenium* Spesies : *Asplenium nidus*	Epiphyte On A Tree		-	37	19	56
14.	Kingdom: Plantae Divisi: Pteridophyta Kelas: Polypoiopsida Ordo: Athyriales Famili : Athyriaceae Genus : *Dilazium* Spesies : *Dilazium esculentum*	Moist Soil		76	93	84	253

15.	Kingdom: Plantae Divisi: Pteridophyta Kelas : Polypodiopsida Ordo: Cyatheales Famili : Cyatheaceae Genus : Cyathea Spesies : *Cyathea contaminans*	Moist Soil		21	38	14	73
16.	Kingdom: Plantae Divisi: Pteridophyta Kelas: Polypodiopsida Ordo : Equisetales Famili : Equisetaceae Genus: *Equisetum* Spesies: *Equisetum ramosissimum*	Sandy Soil		39	19	-	58

2. Dominance Index (C)

Based on the research results, the dominance index values for all three study sites fell into the low category. For further details, please refer to Figure 2 below:

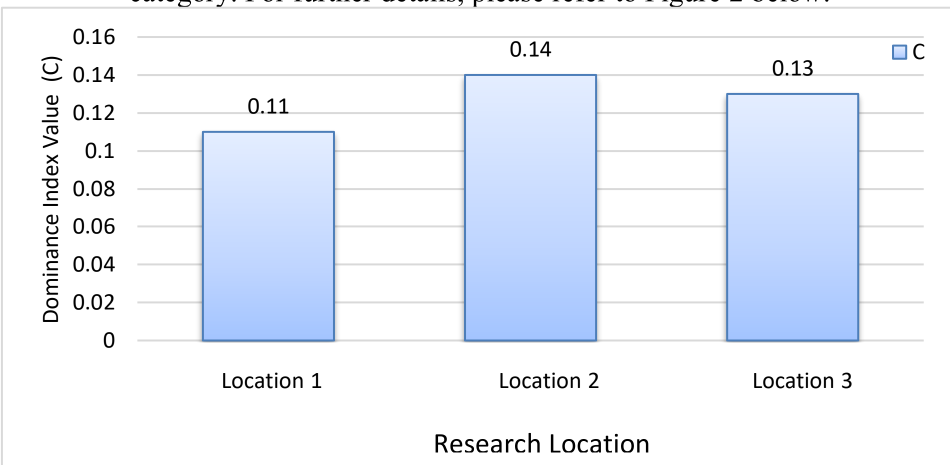

Figure 2. Dominance index of pteridophytes

Based on the calculated dominance index (C) values, all study sites exhibited a low level of dominance, ranging from 0.11 to 0.14. These low values indicate the absence of any single absolutely dominant Pteridophyte species, suggesting a relatively even distribution of individuals within the Pteridophyte communities at each site.

3. Correlation of Environmental Factors

Based on measurements of four environmental parameters temperature, air humidity, light intensity, and soil pH data on environmental factors were obtained, as presented in Table below.

Table 2. Environmental Factors

Parameter	location		
	1	2	3
Temperature (°C)	31°C-34°C	26°C-27°C	26°C-29°C
air humidity (%)	56%	66%	68%
Light intensity (lux)	505	571	446
Soil pH	5,5-7	5,5-6	5,5-7

Principal Component Analysis (PCA) reveals the influence of environmental parameters on the diversity and dominance indices of Pteridophyta species across three study sites, each exhibiting distinct characteristic trends. Site 1 is characterized by temperatures ranging from 31–34°C, a factor strongly associated with

Pteridophyta diversity. Site 2 presents a different profile, dominated by the highest light intensity among the three sites, alongside lower temperatures and relatively high air humidity. Meanwhile, Site 3 is characterized by the highest air humidity, the lowest light intensity, and low temperatures. The PCA results indicate that temperature is the environmental factor exerting the greatest influence on Pteridophyta diversity. Conversely, the relatively uniform soil pH recorded at 6 across all sites suggests that this parameter does not contribute significantly to differentiating the environmental characteristics between the locations.

Pteridophyte plant communities along the river in Tiganderket District exhibit moderate diversity (H'= 2.16–2.36) and very low dominance indices (0.11–0.14), indicating a stable riparian ecosystem free from absolute resource monopolization by any single species (Magurran, 2021; Yolla et al., 2022). Spatially, the highest diversity and lowest dominance were observed in the upstream section, attributed to high habitat heterogeneity regarding growth sites. Conversely, the midstream section presents more optimal environmental conditions (Indri et al., 2019), while the downstream section demonstrates a well-balanced community relative to its environment (Sari et al., 2021). Overall, the area hosts 16 species across 7 families; *Nephrolepis hirsutula* is the dominant species due to its high tolerance for diverse substrates, whereas *Pteris vittata* is the least abundant, owing to its narrow habitat specificity (Indri et al., 2019).

The structural dynamics of these Pteridophyte communities are heavily governed by micro- and macro-abiotic factors; Principal Component Analysis (PCA) confirms that microclimatic physical factors (temperature, humidity, and light) are the primary determinants, outweighing chemical factors such as soil pH, which remains uniform at 6 (Silva et al., 2018). The communities in this area possess a flexible temperature tolerance range (26–33°C), provided that tissue aeration requirements are met (Sundue et al., 2020). The balance observed in the downstream section is supported by ideal humidity (68%) and shaded light intensity (446 lux), conditions crucial for spermatozoan fertilization. Conversely, high light exposure in the middle section of the river (571 lux) drives up surface temperatures and evaporation rates, thereby selecting only drought-tolerant species capable of survival (Indri et al., 2019).

The presence of these 16 stably distributed species serves as a positive bioindicator of ecological recovery following the Mount Sinabung eruption. In the successional dynamics of land buried by volcanic material, Pteridophytes play a crucial role as pioneer plants; this is due to their production of microscopic, protective-coated units capable of remaining dormant and rapidly germinating into prothalli when micro-environmental moisture levels are sufficient (Tjitrosoepomo, 2014). Their root systems, comprising fibrous roots and rhizomes, mechanically grip the loose volcanic substrate, inhibit erosion, and stabilize riparian soil. Furthermore, the ecological decomposition of dead biomass gradually forms a humus layer that improves the substrate's physical and chemical properties thereby facilitating the creation of new ecological niches and paving the way for advanced floral succession in the area.

CONCLUSION

Based on the study of Pteridophyte diversity along the river in Tiganderket District, it can be concluded that the diversity index values (H’) for Pteridophytes across all study sites fall into the moderate category. The diversity index values were 2.36 for Site 1, 2.16 for Site 2, and 2.18 for Site 3. A total of 16 species spanning 7 families were identified, with Thelypteridaceae being the most dominant family. Observations revealed that *Nephrolepis hirsutula* was the most abundant species, and that temperature, an environmental factor was associated with Pteridophyte diversity at the study sites. This study was limited to a specific observation period and did not include continuous monitoring of succession processes in the river area affected by cold lava flows. Future research should incorporate periodic, long-term monitoring to obtain more comprehensive and diverse data regarding ecosystem succession in areas impacted by volcanic eruptions..

AUTHORS CONTRIBUTION

Enca Pepayosa designed and conducted the research, analyzed and interpreted the data, and drafted the manuscript. Mawardi and Tri Mustika Sarjani analyzed and interpreted the data, reviewed the manuscript, and supervised the entire process.

CONFLICT OF INTEREST

The authors declare no conflicts of interest, and will take full responsibility for the content of the article, including implications of AI-generated art.

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