JPPIPA 11(5) (2025)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

Diversity of Ferns (*Pteridophyta*) in the Dieng Valley Tourism Area

Dilla Shafira Madania[1], Erlita Chandra Karina Putri[1], Helmi Adi Guna[1], Syifa' Hajidah Aziz[1], Wulan Madya Rani[1], Indra Fardhani[1*]

[1] Science Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang, Indonesia.

Received: December 18, 2024
Revised: March 28, 2025
Accepted: May 25, 2025
Published: May 31, 2025

Corresponding Author:
Indra Fardhani
indra.fardhani.fmipa@um.ac.id

DOI: 10.29303/jppipa.v11i5.10092

Abstract: Indonesia is rich in biodiversity, especially in its flora. Biodiversity is the various forms of life that exist on land, air and water in a space and time, whether in the form of plants, animals, even the smallest living things such as microorganisms. One type of plant that has a lot of biodiversity in Indonesia is ferns (Pteridophyta). Ferns are Cormophyta spore plants that can live in various habitats, either as epiphytes, terrestrial plants, or as aquatic plants. The purpose of this study was to determine the diversity of ferns in the Dieng Valley. Daui District, Malang Regency. The research method used is a descriptive method with a purposive sampling technique, namely sampling based on certain criteria. Data collection was carried out through the exploration method, where researchers made direct observations of fern species (Pteridophyta). Species identification was carried out using the Picture This and Google lens applications. Data analysis was carried out by calculating the Diversity Index. The results of the study obtained were that in the Dieng Valley area, the pteris vittata species was found to be more dominant. These ferns were found in various research locations.

Keywords: Dieng Valley; Diversity; Ferns

Introduction

One of the plants that has high diversity in Indonesia is ferns (Pteridophyta). There are an estimated 10.000 species of ferns in the world, in Indonesia there are around 2.97 species or around 22% of ferns that grow, and as many as 630 species of which are found on the island of Java (Ibrahim et al., 2024). Ferns are spore-bearing Cormophyta plants that can live in various habitats, both as epiphytes, terrestrial plants, and as aquatic plants (Praptosuwiryo et al., 2019; Dani et al., 2024). Ferns are vascular plants that do not flower but have spores (Plackett et al., 2015; Sessa & Der, 2016). Ferns, although they have many benefits, are often forgotten and rarely the focus of research compared to other plant groups (Pilcher & Cortazzi, 2024; Kujala et al., 2022; Samal & Dash, 2023). According to Beeson et al. (2020), Davallia trichomanoides and Nephrolepis hirsutula can be used as ornamental plants. In addition, the people of West Papua also consume the Diplazium esculentum species as vegetables and eaten every day (Rani et al., 2023). Based on research by Hori et al. (2022), which has been conducted in the Gedong Songo Temple Area, Semarang Regency, the diversity of fern species (Pteridophyta) in the Gedong Songo Temple Area, Semarang Regency consists of 18 species belonging to 11 families.

The types of ferns (Pteridophyta) that are abundant in the Gedong Songo Temple Area, Semarang Regency are Gleichenia linearis, Histiopteris incisa, Lycopodium cernuum, and Nephrolepis sp. Environmental factors in the Gedong Songo Temple Area, Semarang Regency are still suitable for the growth of ferns. Dieng Valley Tourism Park is one of the most visited tourist

How to Cite:
Madania, D. S., Putri, E. C. K., Guna, H. A., Aziz, S. H., Rani, W. M., & Fardhani, I. (2025). Diversity of Ferns (Pteridophyta) in the Dieng Valley Tourism Area. *Jurnal Penelitian Pendidikan IPA*, *11*(5), 593–603. https://doi.org/10.29303/jppipa.v11i5.10092

destinations in Malang Regency. This tourist park is located on Jalan Wisata No. 99, Kalisongo Village, Dau District, Malang Regency. This Dieng Valley tourist park has an artificial lake that is usually used for fishing activities (Akram et al., 2023). In the Dieng Valley lake, there are many green plants that grow well so that it looks beautiful. In addition to the artificial lake, there is also a swimming pool. It is very unfortunate, currently the condition of the Dieng Valley tourist park is not well maintained so that it is quiet.

There is no data information regarding the diversity of fern species in the area. Therefore, research was conducted on the diversity of fern species in the area. The purpose of this study was to determine the biodiversity of ferns (Pteridophyta) in the Dieng Valley Tourist Area.

Method

Place and Time of Implementation

This research was conducted on November 18, 2024 in Lembang Dieng, Dau District, Malang Regency. The research was conducted at around 10.00 WIB to 13.00 WIB.

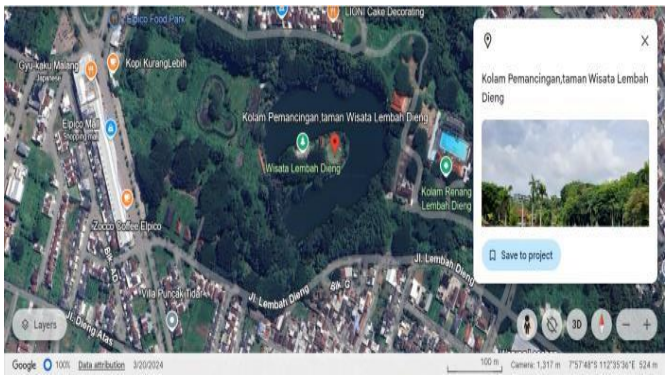

Figure 1. Research location

The sampling points consisted of 3 locations, namely far from the lake, close to the lake and the forest around the Dieng Valley lake area.

Figure 2. Sampling points

Tools and Materials

The tools used in this study include: a meter to measure the observation location, stationery to record things needed in the observation, Picture this. Application features on smartphones used to identify Pteridophyta plants, google lens. Application features on smartphones used to identify pteridophyta plants, camera. Used to document Pteridophyta plants; Thermohygrometer. Used to measure air temperature and humidity

Data Collection Method

The research method used to conduct research on the diversity of fern species (Pteridophyta) is a descriptive method with a purposive sampling technique, namely sampling based on certain criteria. These criteria include location and environmental conditions. The research was conducted in the Dieng Valley which has unique environmental conditions, such as a cool climate and fertile soil that can support the growth of various types of Pteridophyta. Data collection was carried out using the method exploration, starting from the entrance of the Dieng Valley to the area near the lake. The samples taken were ferns found in three different locations, namely the area far from the lake (± 50 m), the area near the lake, and the forest area around the lake (± 5 m from the lake).

Data collection was carried out through the exploration method, where researchers made direct observations of fern species (Pteridophyta) and recorded environmental conditions, namely humidity and environmental temperature. Species identification was carried out in stages to ensure the accuracy of the results. The steps taken began by using the Picture This and Google lens applications to assist in providing initial identification based on images taken from the field. After obtaining initial results, they were further verified using determination keys and various relevant botanical literature. Documentation was carried out in detail to support the morphological description of ferns (Pteridophyta). Each specimen was photographed to capture morphological characteristics such as leaf shape, stem size, etc. In addition, field notes were arranged systematically to record important information and support further analysis (Khirfan et al., 2020; Maher et al., 2018).

Data Analysis

Data analysis was carried out by calculating the Diversity Index. The most common diversity index is the Shannon-Weaners species diversity index, which has the following formula equation:

$$\hat{H} = -\sum_{i-1}^{s}\left(\frac{ni}{N}\right)\ln\left(\frac{ni}{N}\right) \quad (1)$$

Description: H' = Species diversity index ni = Number of i-th individuals; N = Total number of individuals of all species ln = Logarithm of base numbers (normal) s = number of species. The greater the value of Ĥ indicates the higher the species diversity of a plant community in an ecosystem. The value of species diversity is defined as follows: Ĥ > 3 indicates high species diversity in an area; 1 ≤ Ĥ ≤ 3 indicates moderate species diversity in an area; Ĥ < 1 indicates low species diversity in an area.

Result and Discussion

The research was conducted in the Dieng Valley tourist area, Dau District, Malang Regency, East Java. This activity was carried out on November 18, 2024, starting at 10:00 WIB to 13:00 WIB. Based on the results of the identification of ferns in the Dieng Valley area at several predetermined points covering 3 points, namely the area far from the lake location (the entrance to the Dieng Valleylake), the area near the Dieng Valleylake, and the forest area around the Dieng Valley.

First Research Location

Figure 3. The first location of the study in the Dieng Valley area

From the first location, namely in an area far from the lake location (the entrance to the Dieng Valley Lake), ferns were found attached to trees and on the ground, namely:

Pteris linearis

Figure 4. Pteris linearis

Classification of pteris linearis:
Kingdom: Plantae
Subkingdom: Tracheobionta
Division: Pteridophyta
Class: Pteridopsida
Subclass: Polypoditae
Order: Polypodiales
Family: Pteridaceae Genus: Pteris
Species: Pteris linearis Poir

Based on the results of observations and identification, this fern has the Latin name Pteris linearis. This plant has distinctive morphological characteristics, including pinnate compound leaves with long, narrow, linear blades, green in color, and a smooth surface. Young leaves show the typical characteristics of ferns in the form of rolled leaf tips (circinate vernation). The rhizome is in the form of a rhizome that grows horizontally and is covered by small scales that function to protect the rhizome structure. The sorus structure, which is a collection of sporangia, is located on the lower edge of the leaf (marginal) without being protected by the indusium, so that the sporangia are directly visible. The stem is reduced to a rhizome that functions as a connection between the roots and leaves, while the roots are in the form of fibers that play a role in absorbing water and nutrients and attaching plants to the substrate.

Phlebodium aureum

Figure 5. Phlebodium aureum

Classification of Phlebodium aureum:
Kingdom: Plantae
Subkingdom: Tracheobionta
Division: Pteridophyta
Class: Pteridopsida
Subclass: Polypoditae
Order: Polypodiales
Family: Polypodiaceae
Genus: Phlebodium
Species: Phlebodium aureum (L.)

Based on the results of observations and identification, this fern has the Latin name Phlebodium

aureum. This plant has distinctive morphological characteristics as one of the epiphytic ferns. The leaves are single with a finger shape (pinnatifid), bluish green in color, and the surface of the leaves is coated with a layer of wax that makes it look shiny. The size of the leaves is relatively large, depending on the growing conditions. The rhizomes are creeping, thick, and covered with fine golden brown hairs, which are characteristic of this plant. The stem is reduced and functions as a support and connection between the roots and leaves. The roots are fibrous and able to attach to substrates, such as tree trunks, allowing this plant to live as an epiphyte.

Pteris Vittata L.

Figure 6. Pteris Vittata L.

Classification of Pteris Vittata L.:
Kingdom: Plantae
Subkingdom: Tracheobionta
Division: Pteridophyta
Class: Pteridopsida
Subclass: Polypoditae
Order: Polypodiales
Family: Pteridaceae
Genus: Pteris
Species: Pteris vittata L.

The fern with the Latin name Pteris Vittata L. is a species of fern that likes humidity, this species is often found on the ground, walls and even steep cliffs. This species has rhizomes that spread and enter the cracks in the rocks. Based on the results of observations, Pteris Vittata L. has morphological characteristics, namely compound pinnate leaves with pointed tips, long in shape, has flat leaf edges and a rather rough leaf surface texture. The size of the leaves of this species is shorter towards the bottom and the size of the leaves is longer towards the top. The arrangement of the leaves on Pteris Vittata L. is opposite or crossed. From the second location, namely in the forest area near the river.

Second Research Location

Figure 7. The second research location in the Dieng Valley

Location in the Dieng Valley, 5 m from the lake, found ferns on the ground and attached to the paving walls, as follows:

Cyclosorus interruptus

Figure 8. Cyclosorus interruptus

Classification of Cyclosorus interruptus:
Kingdom: Plantae
Division: Tracheophytes
Class: Polypodiopsida
Order: Polypodiales
Family: Thelypteridaceae
Genus: Cyclosorus
Species: Cyclosorus interruptus

The fern with the Latin name Cyclosorus interruptus is a species that lives in humid habitats and is supported by puddles. This species is often found in places with high water content. Based on the results of observations, Cyclosorus interruptus has morphological characteristics, namely the shape of its leaves which are elongated with serrated leaf edges and have pointed leaf tips. According to Zuo et al. (2025), this fern has round sori. However, during the observation, no sori were found on this fern.

Tectaria harlandii

Figure 9. Tectaria harlandii

Classification of Tectaria harlandii
Kingdom: Plantae
Phylum: Tracheophyta
Class: Polypodiopsida
Order: Polypodiales
Family: Tectariaceae
Genus: Tectaria
Species: Tectaria harlandii (Hook.) C.M. Kuo

The fern with the Latin name Tectaria harlandii is a species that grows in humid environments and is often found in tropical forests. Based on observations, Tectaria harlandii has distinctive morphological characteristics. The leaves are pinnately compound with long, narrow, and linear leaf blades, dark green to light green in color, and have a smooth surface. Young leaves show the typical characteristics of ferns with curled tips (circinate vernation). The rhizome is in the form of a creeping rhizome, covered with small brown scales. The leaf stalks are brownish green and are often covered with fine hairs. Sorus, which is a collection of sporangia, is located on the lower surface of the leaf (abaxial) and is not protected by the indusium, so that the sporangia are directly visible. The stem is reduced to a rhizome that functions as a connection between the roots and leaves, while the roots are fibrous which function to absorb water and nutrients while attaching the plant to the substrate. Tectaria harlandii can be found in humid areas such as riverbanks or in shady forests, making it an important part of the tropical forest ecosystem.

Nephrolepis biserrate
Classification of *Nephrolepis biserrata:*
Kingdom: Plantae
Division: Pteridophyta
Class: Polypodiopsida
Order: Polypodiales
Family: Nephrolepidaceae
Genus: Nephrolepis
Species: Nephrolepis biserrata (Sw.) Schott

Figure 10. Nephrolepis biserrata

The fern with the Latin name Nephrolepis biserrata is a species that is often found in humid areas and can grow both as an epiphyte and terrestrial. Based on observations, Nephrolepis biserrata has distinctive morphological characteristics. The leaves are pinnately compound with long, narrow, and lanceolate leaf blades, green in color, and have a smooth surface. The tip of the leaf shows the typical characteristics of a fern by rolling (circinate vernation). The rhizome is in the form of an upright rhizome with dense leaves, often covered by fine light brown hairs that fall off easily. Sorus, which is a collection of sporangia, is located along the lower edge of the leaf (marginal) without being protected by the indusium, so that the sporangia are directly visible. The stem is reduced to a rhizome that functions as a connection between the roots and leaves, while the roots are fibrous in shape that function to absorb water and nutrients while attaching the plant to the substrate. Nephrolepis biserrata can be found in various habitats such as roadsides, open fields, and humid areas, making it an important part of the tropical forest ecosystem.

Phymatosorus scolopendria

Figure 11. Phymatosorus scolopendria

Classification of Phymatosorus scolopendria:
Kingdom: Plantae
Division: Pteridophyta
Class: Pteridopsida
Order: Polypoditae

Family: Polypodiaceae
Genus: Phymatosorus
Species: Phymatosorus scolopendria

Phymatosorus scolopendria has a habit of growing attached to other tree trunks (epiphytes) and forming rhizome root tubers. This plant comes from the dry tropical biome in the tropical and subtropical regions of Africa, Europe, and Asia. This fern has broad, glossy leaves that have wart-like protrusions on the surface. It is native to Hawaii and prefers full sun to partial shade. This is a slow-growing fern. The leaves when crushed have a musky aroma.

Macrothelypteris torresiana

Figure 12. *Macrothelypteris torresiana*

Classification of *Macrothelypteris torresiana:*
Kingdom: Plantae
Division: Pteridophyta
Class: Pteridopsida
Order: Polypodiales
Family: Aspleniaceae
Genus: Macrothelypteris
Species: Macrothelypteris torresiana

Macrothelypteris torresiana is one of the perennial plant species from the Aspleniaceae family. This plant comes from a tropical wet biome that is spread from the western Indian Ocean, tropical and subtropical Asia to the Pacific. This type of fern is characterized by large, smooth leaves that grow well in humid and shady forest environments. This plant often forms a dense green carpet on the forest floor, helping to maintain soil moisture and providing a habitat for microorganisms. The striking triangular shape of the fern's fronds and finely segmented leaves allow it to effectively capture light and moisture, which is essential for its growth in the competitive subterranean ecosystem.

Christella dentate

Christella dentata is a plant that grows in humid places, especially in rocky places. This plant has dark fibrous roots that branch dichotomously. When young, it has a watery stem, then changes to woody after the stem is mature. This plant is used as a traditional medicine, namely as an antimicrobial because it has the potential to fight Bacillus subtilis, Escherichia coli, Salmonella typhi, and Staphylococcus aureus. The location of the spores is under the leaf surface (Abdillah et al., 2024).

Figure 13. *Christella dentata*

Classification of Christella:
Kingdom: Plantae
Division: Pteridophyta
Class: Polypodiopsida
Order: Polypodiales
Family: Thelypteridaceae
Genus: Christella Lev.
Species: Christella dentata

Adiantum capillus veneris

Figure 14. *Adiantum capillus-veneris*

Classification of Adiantum capillus-veneris:
Kingdom: Plantae
Division: Pteridophyta
Class: Polypodiopsida
Order: Polypodiales
Family: Pteridaceae
Genus: Adiantum
Species: Adiantum capillus-veneris

Adiantum capillus-veneris is a plant that grows in humid places, especially on the ground. At the beginning of its growth, the leaves of this plant are pale green, then turn green as it grows. The leaves of this plant are spaced apart with pinnate leaf veins and are shaped like a spade. The stem is round and elongated with a smooth surface and is brown in color (Ondikeleuw et al., 2024). This plant has fibrous roots. The sorus is located under the surface of the leaf which is on the edge of the leaf. When young, the sorus is white and will turn brown when old. It has a habit of growing attached to other tree trunks (epiphytes). This fern can also be used as an ornamental plant (Hasanah et al., 2021; Cronin et al., 2024).

Third Research Location

Figure 15. The third location of the study in the Dieng Valley

From the third location, namely in the area near the lake, only 1 type of fern was found, namely: Pteris vittata L.

Figure 16. *Pterris vittata*

Classification of Pteris Vittata L.
Kingdom: Plantae
Subkingdom: Tracheobionta
Division: Pteridophyta
Class: Pteridopsida
Subclass: Polypoditae
Order: Polypodiales
Family: Pteridaceae Genus: Pteris
Species: Pteris vittata L.

The fern with the Latin name Pteris Vittata L. is a species of fern that likes humidity, this species is often found on the ground, walls and even steep cliffs. This species has rhizomes that spread and enter the cracks in the rocks. Based on observations, Pteris Vittata L. has morphological characteristics, namely compound pinnate leaves with pointed tips, long in shape, has flat leaf edges and a rather rough leaf surface texture. The size of the leaves of this species is shorter towards the bottom and the size of the leaves is longer towards the top. The leaf arrangement of Pteris Vittata L. is opposite or crossed. According to (Pantiwati et al., 2022), Pteris vittata has a characteristic that is only owned by it, namely, relatively short leaf stalks with simple leaf edges. As if attached to the stem, and has long leaflets. This type will be seen to have a short light green stem and is covered with dark brown scales when mature. The leaf stalk can reach 40 cm.

Diversity of Ferns

The diversity of ferns in the Dieng Valley, Dau District, Malang Regency shows significant variation with the discovery of 10 types of ferns, namely Adiantum capillus-veneris, Christella dentata, Macrothelypteris torresiana, Phymatosorus scolopendria, Pteris vittata, Nephrolepis biserrata, Tectaria harlandii, Cyclosorus interruptus, Pteris linearis, and Phlebodium aureum. These ferns show adaptation to their diverse habitats, both as epiphytes and terrestrials, which indicate the high diversity of ecosystems in the area.

Fern Habitat

A total of 10 types of ferns can be identified from 2 types of ferns, namely epiphytes and terrestrials. Epiphytic ferns are ferns that attach themselves to other plants. 3 epiphytic ferns were found, namely Adiantum capillus-veneris, Phlebodium aureum, Nephrolepis biserrata. While terrestrial ferns are ferns that live on the surface of the soil in humid environments. 7 terrestrial ferns were found, namely Christella dentata, Macrothelypteris torresiana, Phymatosorus scolopendria, Pteris vittata, Tectaria harlandii, Cyclosorus interruptus, Pteris linearis.

Diversity Index of Ferns in Dieng Valley, Dau District, Malang Regency

The diversity index can be used to measure the condition of an ecosystem, an ecosystem is said to be stable if it has a high diversity index. Table 1 shows that overall the fern diversity index in the Dieng Valley Tourism Park, Dau District, Malang Regency is included in the moderate category, which is 2.26. This is in accordance with the criteria for the species diversity index according to Rambe et al. (2021), the range of

diversity grouping is said to be in the low category if H'<1, moderate category if 1≤H'≤3, and high category if H'>3. The level of the fern diversity index found in the Dieng Valley Tourism Park shows that H' is included in the moderate category, namely 2.26. The parameters of the Physico-Chemical factors at the research location are air temperature, sunlight intensity, and location points. The physical and chemical parameters of the environment in the research area were carried out using technology found on smartphones (Chandra Kishore et al., 2022). These physical parameters include environmental temperature, sunlight intensity, and altitude at the observation point, namely the Dieng Valley Tourism Park located in Kalisongo Village, Dau District, Malang Regency.

Table 1. Diversity Index of Fern Species in Dieng Valley Tourism Park

Family	Species	Number of Species	H'
Pteridaceae	*Pteris linearis*	21	-0,19
	Adiantum capillus-veneris	36	-0,26
	Pteris vittata	45	-0,29
Polypodiaceae	*Phlebodium aureum*	19	-0,18
	Phymatosorus scolopendria	23	-0,20
Tectariaceae	*Tectaria harlandii*	20	-0,18
Nephrolepidac eae	*Nephrolepis biserrata*	42	-0,28
Aspleniaceae	*Macrothelypteri s torresiana*	33	-0,24
Thelypteridac eae	*Christella dentata*	40	-0,27
	Cyclosorus interruptus	18	-0,17
Total		297	2.26

Temperature and Humidity

The diversity of ferns found in the three locations in the Dieng Valley tourist area is influenced by environmental factors (Table 2). At locations near the lake, the average temperature is 32°C with an air humidity of 82%, at locations far from the lake, the average temperature is 32°C with an air humidity of 82% and in forest areas, the average temperature is 30°C with an air humidity of 90%. The good temperature for the growth of ferns varies (Huang et al., 2025). According to Kawichai et al. (2025), Johnson et al. (2020), De Jesus et al. (2021), Chang et al. (2024), the good temperature for the growth of tropical ferns is in the range of 21-27°C with a humidity of 60% -80%. According to Dai et al. (2020), Umair et al. (2023), Sianturi et al. (2021), and Oseguera-Olalde et al. (2022), the level of fern diversity is higher in humid and cool areas, the diversity will be lower in areas with high temperatures. Based on these results, the three locations have ideal humidity levels for fern growth.

Another environmental factor that plays a role in the growth of ferns is light intensity. At locations near the lake, the light intensity is 520 (lux), at locations far from the lake 512 (lux) and the forest area is 472 (lux). There is a significant difference between areas near the lake, far from the lake and the forest area. This is because the forest has dense and dense plants compared to the two locations. High air humidity makes the light intensity in the forest area low. This is in accordance with the opinion of Naveed et al. (2024), Yu et al. (2023), Kerstiens (1994), Chia et al. (2022), that high humidity is caused by low light intensity. The results of the study showed that the Dieng Valley has significant potential as a habitat for various types of ferns.

Figure 17. Temperature and humidity in areas near the lake and areas far from the lake when measured using a smartphone

Figure 18. Temperature and humidity in forest areas when measured using a smartphone

Table 2. Environmental Factors

	Near the lake	Far from the lake	Forest Area
Temperature (°C)	32	32	30
Air Humidity (%)	82%	82%	90%
Light Intensity (lux)	520	512	472

The dominant ferns found on the soil substrate, and trees indicate that the environmental conditions in this area support optimal growth. Factors such as high air humidity, adequate lighting, and a natural environment play an important role in supporting the existence and development of ferns in this area (Driesen et al., 2020; Kermavnar et al., 2023). The diversity index of fern species in the Dieng Valley Tourism Park, Dau District, Malang Regency is included in the moderate category, which is 2.26, which indicates that this area has quite a lot of fern species. This area has the opportunity to increase the diversity of ferns through natural conservation (Delos Angeles et al., 2025; Corlett, 2016).

Conclusion

In the Dieng Valley Tourism Area, Dau District, Malang Regency, it shows that this area has a diversity of fern species in the moderate category, namely 2.26. The fern that is often found in this area is Pteris vittata L. which grows in areas near lakes and forests around the lake that are 5 m away. Based on research, various species of ferns are found in various substrates, including soil, rocks, and trees. This diversity reflects the quality of the Dieng Valley environment that supports the growth of ferns, with high air humidity and sufficient light intensity. Ferns in this area play an important role in the ecosystem, such as maintaining soil stability and supporting local biodiversity. The diversity of fern species in the Dieng Valley shows the importance of this area as a natural habitat that supports the life of various types of ferns.

Acknowledgments
Thanks to all parties who have supported the implementation of this research. I hope this research can be useful.

Author Contributions
Conceptualization; D. S. M.; methodology.; E. C. K. P.; validation; H. A. G.; formal analysis; S. H. A.; investigation.; W. M. R; resources; I. F; data curation: D. S. M.; writing—original; E. C. K. P.; draft preparation. E. C. K. P.; writing—review and editing: H. A. G.; visualization: W. M. R. All authors have read and agreed to the published version of the manuscript.

Funding
Researchers independently funded this research.

Conflicts of Interest
The authors declare no conflict of interest.

References

Abdillah, L. N., Suryanto, D., Nurtjahja, K., & Mamangkey, J. (2024). Preliminary Study on Potential Bacterial Species Introducing Antibacterial Agent from Sponge in Unggeh Island Central Tapanuli, Indonesia. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 3780–3786. https://doi.org/10.29303/jppipa.v10i7.8264

Akram, H., Hussain, S., Mazumdar, P., Chua, K. O., Butt, T. E., & Harikrishna, J. A. (2023). Mangrove Health: A Review of Functions, Threats, and Challenges Associated with Mangrove Management Practices. *Forests*, *14*(9), 1698. https://doi.org/10.3390/f14091698

Beeson, R. C., Kjelgren, R., & Chen, J. (2020). Daily Water Requirement of Container Grown Davallia bullata and Nephrolepis exaltata and Implication in Irrigation Practices. *Water*, *12*(8), 2190. https://doi.org/10.3390/w12082190

Chandra Kishore, S., Samikannu, K., Atchudan, R., Perumal, S., Edison, T. N. J. I., Alagan, M., Sundramoorthy, A. K., & Lee, Y. R. (2022). Smartphone-Operated Wireless Chemical Sensors: A Review. *Chemosensors*, *10*(2), 55. https://doi.org/10.3390/chemosensors10020055

Chang, M. M. Y., Hsu, P.-S., Yang, E.-C., Sun, S.-J., & Ho, C.-K. (2024). Warming induces short-term phenological shifts in pollinator-plant interactions that enhance larval development in honey bee. *PLOS ONE*, *19*(12), e0314791. https://doi.org/10.1371/journal.pone.0314791

Chia, S. Y., & Lim, M. W. (2022). A critical review on the influence of humidity for plant growth forecasting. *IOP Conference Series: Materials Science and Engineering*, *1257*(1), 012001. https://doi.org/10.1088/1757-899X/1257/1/012001

Corlett, R. T. (2016). Plant diversity in a changing world: Status, trends, and conservation needs. *Plant Diversity*, *38*(1), 10–16. https://doi.org/10.1016/j.pld.2016.01.001

Cronin, K., Hutton, I., & Burns, K. C. (2024). Harsh environmental conditions promote cooperative behavior in an epiphytic fern. *Plant Signaling & Behavior*, *19*(1), 2335453. https://doi.org/10.1080/15592324.2024.2335453

Dai, X., Chen, C., Li, Z., & Wang, X. (2020). Taxonomic, Phylogenetic, and Functional Diversity of Ferns at

Three Differently Disturbed Sites in Longnan County, China. *Diversity*, *12*(4), 135. https://doi.org/10.3390/d12040135

Dani, D. P., Suleman, S. M., & Febriawan, A. (2024). The Relationship of Terrestrial Fern Species (Pteridophyta) at Salodik Waterfall Central Sulawesi Based on Morphological Characteristics. *Jurnal Biologi Tropis*, *24*(2), 106–112. https://doi.org/10.29303/jbt.v24i2.6714

De Jesus, F. L. F., Sanches, A. C., De Souza, D. P., Mendonça, F. C., Gomes, E. P., Santos, R. C., Santos, J. E. O., & Da Silva, J. L. B. (2021). Seasonality of biomass production of irrigated Mombaça 'Guinea grass.' *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science*, *71*(3), 156–164. https://doi.org/10.1080/09064710.2020.1863456

Delos Angeles, M. D., Radbouchoom, S., Ngarega, B. K., Lapuz, R. S., & Schneider, H. (2025). Spatial diversity and distribution of fern and lycophyte species in karst and non-karst landscapes towards conservation needs. *Frontiers in Plant Science*, *16*, 1495796. https://doi.org/10.3389/fpls.2025.1495796

Driesen, E., Van Den Ende, W., De Proft, M., & Saeys, W. (2020). Influence of Environmental Factors Light, CO2, Temperature, and Relative Humidity on Stomatal Opening and Development: A Review. *Agronomy*, *10*(12), 1975. https://doi.org/10.3390/agronomy10121975

Hasanah, U., Hadisunarso, H., & Praptosuwiryo, T. N. (2021). Composition, community structure, and vertical distribution of epiphytic ferns on Cyathea junghuhniana in Gede-Pangrango National Park, Indonesia. *Biodiversitas Journal of Biological Diversity*, *22*(11). https://doi.org/10.13057/biodiv/d221132

Hori, K., Khine, P. K., Fujiwara, T., Shin, T., & Schneider, H. (2022). Thylacopteris minuta (Polypodiaceae), a new fern species from Myanmar. *PhytoKeys*, *199*, 141–153. https://doi.org/10.3897/phytokeys.199.83107

Huang, S., Zhang, G., & Dong, W. (2025). Global Species Diversity Patterns of Polypodiaceae Under Future Climate Changes. *Plants*, *14*(5), 711. https://doi.org/10.3390/plants14050711

Ibrahim, Y., Gurnita, & Karima, E. M. (2024). Identification Of The Diversity Of Fern Plant Types In Mount Masigit Kareumbi Buru Park, Bandung, Indonesia. *Journal of Law and Sustainable Development*, *12*(2), e3174. https://doi.org/10.55908/sdgs.v12i2.3174

Johnson, M. A., Fortna, S., & Manoukis, N. C. (2020). Evaluation of Exclusion Netting for Coffee Berry Borer (Hypothenemus Hampei) Management. *Insects*, *11*(6), 364. https://doi.org/10.3390/insects11060364

Kawichai, S., Kliengchuay, W., Aung, H. W., Niampradit, S., Mingkhwan, R., Niemmanee, T., Srimanus, W., Phonphan, W., Suwanmanee, S., & Tantrakarnapa, K. (2025). The Influence of Meteorological Conditions and Seasons on Surface Ozone in Chonburi, Thailand. *Toxics*, *13*(3), 226. https://doi.org/10.3390/toxics13030226

Kermavnar, J., Kutnar, L., Marinšek, A., & Babij, V. (2023). Are ecological niche optimum and width of forest plant species related to their functional traits? *Flora*, *301*, 152247. https://doi.org/10.1016/j.flora.2023.152247

Kerstiens, G. (1994). Effects of low light intensity and high air humidity on morphology and permeability of plant cuticles, with special respect to plants cultured in vitro. In P. J. Lumsden, J. R. Nicholas, & W. J. Davies (Eds.), *Physiology, Growth and Development of Plants in Culture* (pp. 132–142). Springer Netherlands. https://doi.org/10.1007/978-94-011-0790-7_14

Khirfan, L., Peck, M., & Mohtat, N. (2020). Systematic content analysis: A combined method to analyze the literature on the daylighting (de-culverting) of urban streams. *MethodsX*, *7*, 100984. https://doi.org/10.1016/j.mex.2020.100984

Kujala, J., Sachs, S., Leinonen, H., Heikkinen, A., & Laude, D. (2022). Stakeholder Engagement: Past, Present, and Future. *Business & Society*, *61*(5), 1136–1196. https://doi.org/10.1177/00076503211066595

Maher, C., Hadfield, M., Hutchings, M., & De Eyto, A. (2018). Ensuring Rigor in Qualitative Data Analysis: A Design Research Approach to Coding Combining NVivo With Traditional Material Methods. *International Journal of Qualitative Methods*, *17*(1), 1609406918786362. https://doi.org/10.1177/1609406918786362

Naveed, M., Bansal, U., & Kaiser, B. N. (2024). Impact of low light intensity on biomass partitioning and genetic diversity in a chickpea mapping population. *Frontiers in Plant Science*, *15*, 1292753. https://doi.org/10.3389/fpls.2024.1292753

Ondikeleuw, M., Mene, B., Rumbarar, M. K., Nikmatulah, M., Fairyo, K., Kawer, S. M., Raunsay, E. K., Marsandi, F., & Purnamasari, R. A. (2024). Utilization of Endemic Fruits in Efforts to Conserve Genetic Resources in Jayapura District. *Jurnal Penelitian Pendidikan IPA*, *10*(10), 7250–7258. https://doi.org/10.29303/jppipa.v10i10.9143

Oseguera-Olalde, T. K., Bonilla-Valencia, L., Fonseca, R. M., Martínez-Orea, Y., Lorea-Hernández, F., & Castillo-Argüero, S. (2022). Fern diversity in altitude and anthropogenic gradients in a temperate forest in Mexico City, Mexico. *Trees,*

Forests and People, *10*, 100345. https://doi.org/10.1016/j.tfp.2022.100345

Pantiwati, Y., Sari, T. N. I., & Nurkanti, M. (2022). Learning assessment model in biology education during the COVID-19 pandemic. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, *8*(3), 265–274. https://doi.org/10.22219/jpbi.v8i3.22992

Pilcher, N., & Cortazzi, M. (2024). "Qualitative" and "quantitative" methods and approaches across subject fields: Implications for research values, assumptions, and practices. *Quality & Quantity*, *58*(3), 2357–2387. https://doi.org/10.1007/s11135-023-01734-4

Plackett, A. R. G., Di Stilio, V. S., & Langdale, J. A. (2015). Ferns: The missing link in shoot evolution and development. *Frontiers in Plant Science*, *6*. https://doi.org/10.3389/fpls.2015.00972

Praptosuwiryo, T. N., Sumanto, S., & Cahyaningsih, R. (2019). Diversity and host preferences of ferns and lycopods epiphytes on palm trees. *Biodiversitas Journal of Biological Diversity*, *20*(12). https://doi.org/10.13057/biodiv/d201236

Rambe, I. F., Rambey, R., & Siregar, S. (2021). Species diversity, abundance, and wildlife conservation status in Batang Gadis National Park, North Sumatra, Indonesia. *Biodiversitas Journal of Biological Diversity*, *22*(11). https://doi.org/10.13057/biodiv/d221157

Rani, D. M., Hanafi, N., Sudarko, Rachmawati, D., Siswoyo, T. A., Christianty, F. M., Dewi, I. P., & Nugraha, A. S. (2023). Indonesian Vegetables: Searching for Antioxidant and Antidiabetic Therapeutic Agents. *Drugs and Drug Candidates*, *2*(1), 14–36. https://doi.org/10.3390/ddc2010002

Samal, R., & Dash, M. (2023). Ecotourism, biodiversity conservation and livelihoods: Understanding the convergence and divergence. *International Journal of Geoheritage and Parks*, *11*(1), 1–20. https://doi.org/10.1016/j.ijgeop.2022.11.001

Sessa, E. B., & Der, J. P. (2016). Evolutionary Genomics of Ferns and Lycophytes. In *Advances in Botanical Research* (Vol. 78, pp. 215–254). Elsevier. https://doi.org/10.1016/bs.abr.2016.02.001

Sianturi, A., Ridlo, S., & Retnoningsih, A. (2021). Diversity and distribution of ferns at different altitudes in Central Java. *Journal of Physics: Conference Series*, *1918*(5), 052016. https://doi.org/10.1088/1742-6596/1918/5/052016

Umair, M., Hu, X., Cheng, Q., Ali, S., & Ni, J. (2023). Distribution patterns of fern species richness along elevations the Tibetan Plateau in China: Regional differences and effects of climate change variables. *Frontiers in Plant Science*, *14*, 1178603. https://doi.org/10.3389/fpls.2023.1178603

Yu, W., Jiang, M., Yue, Q., Yang, Y., Luo, Z., Lv, B., He, R., Feng, S., & Yang, M. (2023). Effects of Low-Light Environments on the Growth and Physiological and Biochemical Parameters of Indocalamus and Seasonal Variations in Leaf Active Substance Contents. *Plants*, *12*(23), 3993. https://doi.org/10.3390/plants12233993

Zuo, Z.-Y., Rouhan, G., Dong, S.-Y., Liu, H.-M., Du, X.-Y., Zhang, L.-B., & Lu, J.-M. (2025). A revised classification of Dryopteridaceae based on plastome phylogenomics and morphological evidence, with the description of a new genus, Pseudarachniodes. *Plant Diversity*, *47*(1), 34–52. https://doi.org/10.1016/j.pld.2024.07.010