Fern Diversity as a Baseline for Sustainable Management of Waterfall Ecosystems: A Case Study from Curug Gondoriyo, Semarang, Central Java

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Abstract. Curug Gondoriyo is one of the waterfall tourism areas in Semarang city that has the potential for fern diversity. Ferns can be easily found along the trail to the waterfall location. This study aims to determine the species composition, species diversity index, evenness index, and important value index of ferns in the Curug Gondoriyo waterfall area. The research was conducted at three sites. The sampling technique used a plot measuring 5m x 5m. This study found 23 fern species belonging to 8 different families. Pteridaceae has the most species, with six different species. *Adiantum philippense* had the highest number of individuals with the highest important value index of 57.45%. The species diversity index ranged from 2,07 to 2,63 categorized as medium. The species evenness index ranges from 0,83 to 0,91 categorized as almost evenly distributed. The findings highlight the ecological role of ferns in maintaining microhabitat stability and hydrological balance, providing essential insights for sustainable management of waterfall ecosystems and water resources.

1 Introduction

Ferns are an essential component of terrestrial ecosystems, playing vital ecological roles such as maintaining soil stability, regulating microclimate, and contributing to nutrient cycling and hydrological balance [1],[2]. They are classified as cryptogamic plants characterized by vascular structures with roots, stems, and leaves, and they reproduce through spores stored in sporangia that cluster to form sori [3]. As pioneer vegetation, ferns often dominate early successional stages, supporting soil formation and preventing erosion in humid and shaded environments [4].

Indonesia is recognized for its high fern diversity, with more than 2,000 recorded species, and Java Island ranks third in richness after Papua and Kalimantan [5]. Waterfall ecosystems, with their moist microclimates and stable humidity, provide ideal habitats for fern growth and diversity. Previous studies in various Indonesian waterfall areas have reported a wide range of fern species compositions, dominated by families such as Polypodiaceae and Pteridaceae) [6].

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Although various studies on fern diversity have been conducted in other waterfall and riparian ecosystems in Indonesia, the diversity of ferns in the Curug Gondoriyo Waterfall Region, Semarang, Central Java, has not yet been explored. The area's unique microclimate, continuous water flow, and shaded riparian vegetation provide favorable conditions for fern growth and ecological interactions. Moreover, Curug Gondoriyo has been increasingly developed as an ecotourism destination, where maintaining ecological balance is essential for sustainable management. Investigating fern diversity in this area is therefore important not only for understanding local biodiversity but also for supporting evidence-based conservation and ecosystem management strategies.

This study aims to identify the species composition, diversity index, and evenness index of ferns in the Curug Gondoriyo Waterfall Region. The results are expected to provide valuable baseline data for biodiversity monitoring and contribute to innovative approaches in sustainable waterfall and watershed management, integrating ecological understanding with conservation and community-based tourism.

2 Methods

2.1 Study Area

A sampling of ferns was carried out in the waterfall area of Curug Gondoriyo, located in RT 04, RW 04, Dusun Karang Joho, Gondoriyo Village, Ngaliyan District. The Gondoriyo Waterfall area is geographically located at coordinates 7°00'18"S and 110°19'16"T with an altitude of 130 m above sea level. The research location is divided into three sites (Figure 1): Site 1 (park area), Site 2 (waterfall area), and Site 3 (watershed area).

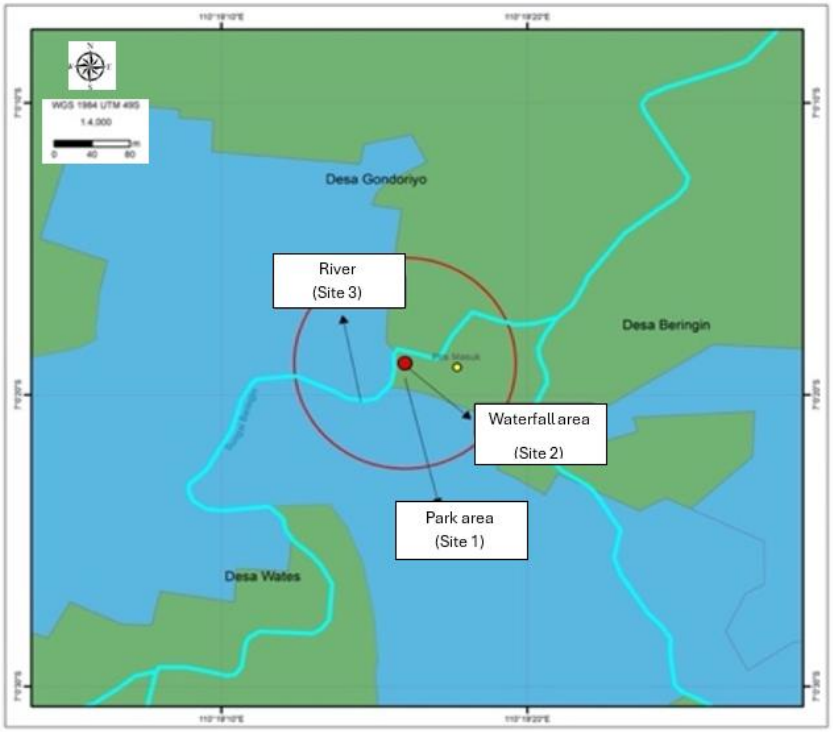

Fig. 1. Map of Research Site in Curug Gondoriyo Waterfall Region

2.2 Sampling Design and Plant Species Identification

This research is an exploratory study using the purposive sampling method. A sampling of ferns was carried out at each site, and plots were made with a size of 5m x 5m with 5 replications. The determination of plot points for each site is done randomly. Each fern species contained in the plot was identified, and the species and number of individuals were recorded.

The identification process is carried out using a fern identification book. *What's that Fern? British Pteridological Society, A Guide to Cumbrian Ferns and Fern-allies, Panduan Lapangan Paku-Pakuan di Taman Margasatwa Ragunan* and fern identification websites: *Plant Systematic, GBIF, Discovery Life Ferns, and Inaturalist*.

2.3 Data Analysis

Data obtained was analyzed using Diversity Index (H'), Important Value Index (IVI), and Evenness Index (E) using the following formulas :

Diversity Index (Shannon-Wiener) (H') [7]

$$H' = -\sum[\left(\frac{ni}{N}\right)\ln\left(\frac{ni}{N}\right)] \quad (1)$$

H'= Shannon-Wiener diversity index; ni = Total of individuals from each species; N = Total of individuals from all species. Criteria for Diversity Index (H') as follows: H' ≥ 3.5 = High; 1.5 < H' ≤ 3.5 = Medium; H' ≤ 1.5 = Low.

Evenness Index (E) [8]

$$E = \left(\frac{H'}{lnS}\right) \quad (2)$$

E = Species evenness index ; H' = Shannon-Wiener diversity index ; S = Total number of species. Criteria for Evenness Index (E) as follows: (E) 0.00 – 0.25 = Uneven; (E) 0.26 – 0.50 = Less evenly distributed; (E) 0.51 – 0.75 = Fairly even distributed; (E) 0.76 – 0.95 = Almost evenly distributed; (E) 0.96 – 1.00 = Evenly distributed.

Important Value Index (IVI) [9]

$$IVI = RD + RF \quad (3)$$

IVI = Important value index; RD = Relative density; RF = Relative frequency.

3 Results and Discussion

3.1 Species Composition

A total of 23 fern species belonging to eight families were identified in the Curug Gondoriyo Waterfall area (Table 1). The family **Pteridaceae** had the highest number of species, comprising six species, followed by **Thelypteridaceae** with five species. **Davalliaceae** and **Polypodiaceae** each consisted of three species, **Athyriaceae** and **Tectariaceae** each contained two species, while **Dennstaedtiaceae** and **Nephrolepidaceae** were represented by only one species each. According to [10], *Pteridaceae* is one of the largest fern families, consisting of approximately 1,000 species across 53 genera worldwide. The *Pteridaceae* species recorded in this study were *Adiantum philippense*, *Pteris biaurita*, *P. ensiformis*, *P. vittata*, *P. wallichiana*, and *Pityrogramma calomelanos*.

Table 1. Species composition of ferns (Pteridophyta) in Gondoriyo Waterfall Area

No	Species	Family	Total of Individuals/ ha		
			St 1	**St 2**	**St 3**
1	Athyriaceae	*Athyrium asplenioides*	2.000	-	2.800
2		*Deparia japonica*	4.400	12.000	2.800
3	Davalliaceae	*Davallia denticulata*	2.000	2.800	6.400
4		*Davallia solida*	-	14.800	-
5		*Davallia trichomanoides*	-	-	3.600
6	Dennstaedtiaceae	*Hypolepis tenuifolia*	-	-	4.800
7	Nephrolepidaceae	*Nephrolepis acutifolia*	-	-	2.400
8	Polypodiaceae	*Drynaria quercifolia*	1.200	-	800
9		*Goniophlebium percussum*	-	-	2.400
10		*Microsorum scolopendria*	-	-	4.400
11	Pteridaceae	*Adiantum philippense*	10.000	43.200	18.800
12		*Pteris biaurita*	18.000	16.800	2.400
13		*Pteris ensiformis*	20.000	4.400	6.800
14		*Pteris vittata*	3.200	-	4.800
15		*Pteris wallichiana*	-	-	2.000
16		*Pityrogramma calomelanos*	6.800	14.800	12.800
17	Tectariaceae	*Tectaria dissecta*	7.600	6.400	-
18		*Tectaria slifolio*	-	5.200	-
19	Thelypteridaceae	*Christella arida*	1.200	-	9.200
20		*Christella dentata*	16.800	-	-
21		*Macrothelypteris torresiana*	8.800	32.00	7.200
22		*Sphaerostephanos heterocarpus*	-	2.800	-
23		*Sphaerostephanos unitus*	-	2.000	3.600
Total of individuals			102.000	128.400	98.000
Total of species			13	12	18

The highest number of individuals was found in Adiantum philippense (72,000/ha), followed by Pteris biaurita (37,200/ha), Pityrogramma calomelanos (34,400/ha), Pteris ensiformis (31,200/ha), and with the lowest number of individuals was Drynaria quercifolia (2,000). /Ha). Adiantum philippense at Site 1 is 10,000/ha, at Site 2 is 43,200/ha, and at Site 3 is 18,800/ha (Table 1). A large number of individuals is due to the excellent distribution potential of Adiantum philippense. The habitat of the Curug Gondoriyo Waterfall area provides favorable conditions for the growth of *Adiantum philippense*. The abundance of rocks and cliffs in the study area creates suitable microhabitats that support its establishment

and expansion. *Adiantum philippense* typically forms clumps in highly humid environments and exhibits high dispersal ability due to the production of numerous spores. However, this species tends to avoid windy areas because its thin fronds are prone to drying and scorching, which is why it is commonly found growing in rock crevices. According to [11], several *Adiantum* species, including *A. philippense*, are also capable of surviving under relatively dry and warm conditions.

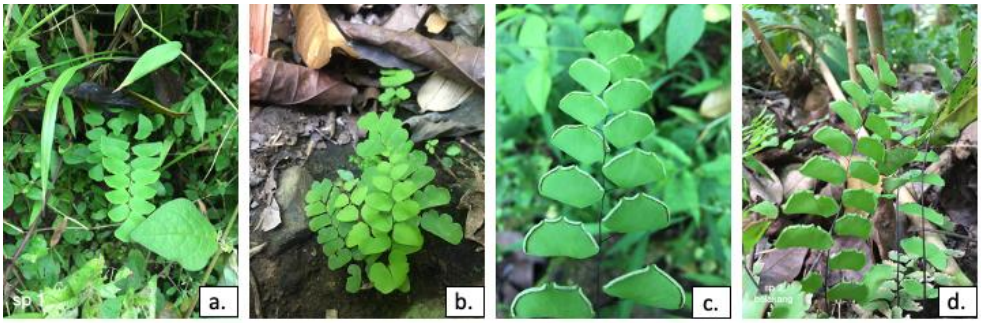

Fig. 2. a. Habitus of *Adiantum philippense* b. *Adiantum philippense* on the rocks c. Adaxial Lamina c. Abaxial Lamina

Drynaria quercifolia was the species with the lowest number of individuals, recorded only at Site 1 and Site 3. Its population density was 1,200 individuals per hectare at Site 1 and 800 individuals per hectare at Site 3. *Drynaria quercifolia* was also the only epiphytic fern species found in the Curug Gondoriyo Waterfall area. This species typically grows epiphytically on large, tall, and mature trees and is commonly found in humid environments. *Drynaria quercifolia* is characterized by its distinctive supporting fronds, which can reach up to 40 cm in length, are broad in shape, and have curved margins. Locally known as the "squirrel head fern," this species is widely cultivated as an ornamental plant.

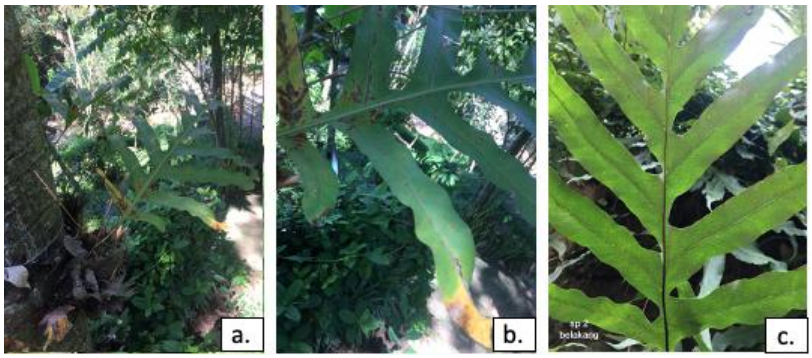

Fig. 3. a. Epifit *Drynaria quercifolia* b. Adaxial Pinna c. Abaxial Pinna

3.2 Diversity (H') and evenness (E) index of fern species

The value of the Shannon-Wiener Diversity Index (H') of ferns in the Curug Gondoriyo waterfall area is categorized as a medium because it is in the diversity value interval from 1.5 to 3.5. The diversity index ranges from 2.07 to 2.63 (Table 2). The value of the diversity index in the Curug Gondoriyo waterfall area is determined by the number of species and the number of individuals of each species. Site 1 has a diversity index value of 2.24 with 13 species found and a total of 102,000/ha (Table 1). Site 2 has a diversity index value of 2.07 with 12 species found and a total of 128,400/ha (Table 1). Site 3 has a diversity index value of 2.63 with 18 species found and a total of 98,000/ha (Table 1). Species diversity is influenced by the distribution of each species because even though a community is large but the distribution is uneven, the diversity is low.

Table 2. Ferns Diversity Index Value in Curug Gondoriyo Waterfall Region

Site	H'	Category
Site 1	2,24	Medium
Site 2	2,07	Medium
Site 3	2,63	Medium

According to [12], environmental factors play a significant role in influencing fern diversity. The results of environmental measurements in the Curug Gondoriyo Waterfall area are presented in Table 3. These environmental variables indicate that the study area provides favorable conditions for fern growth. Hoshizaki and Moran (2001) stated that the optimal temperature range for fern development is between 21°C and 27°C. Although the air temperature in the Curug Gondoriyo Waterfall area is relatively high (30.96°C–34.76°C), ferns are still able to thrive under these conditions. Similarly, [13] reported the presence of 23 fern species in the Suhom Waterfall area, Aceh Besar District, where the average air temperature reached 31°C. Furthermore, [14] noted that the ideal relative humidity for fern growth ranges between 40% and 60%.

Table 3. Environmental Parameters in Curug Gondoriyo Waterfall Region

Parameters	St 1	St 2	St 3
Air Temperature (^{0}C)	32,26	34,76	30,96
Air Humidity (%RH)	68,86	73,9	76,56
Light Intensity (Lux)	278,33	325,66	297,33
Soil pH	6,06	5,86	5,5

The evenness index value (E) shows the level of distribution of individual species in the community. The evenness index value at Site 1 is 0,88, at Site 2 is 0,83, and at Site 3 is 0,91 (Table 4). The evenness index value at Curug Gondoriyo waterfall area is included in the almost uniform category. This indicates that the area has an almost even distribution of species and there is no dominance of certain species. According to [15], a low evenness index value indicates the existence of a species that dominates other species.

Table 4. Ferns Evenness Index Value in Curug Gondoriyo Waterfall Region

Site	E	Category
Site 1	0,88	Almost Evenly Distributed
Site 2	0,83	Almost Evenly Distributed
Site 3	0,91	Almost Evenly Distributed

3.3 Important value index of fern species (IVI)

The importance value index is calculated by adding the relative density (RD) and relative frequency values (RF). Fern species at Site 1 were dominated by *Pteris ensiformis* which had an IVI of 35.61% (Table 5). *Pteris ensiformis* is a type of fern that lives terrestrially on the ground, where Site 1 is a suitable habitat to support its growth properly. Agatha et al. (2019) stated that *Pteris ensiformis* prefers soil substrate and is found primarily in shaded locations on flat terrain, ditch cliffs, river cliffs, and root gaps. This is in accordance with the measurement results of environmental factors at Site 1 that has the lowest light intensity value of 278.33 lux (Table 3) indicating that the area is heavily shadowed due to the presence of many trees. Site 2 and Site 3 are dominated by *Adiantum philippense* which had an IVI of 57.45% at Site 2 (Table 5) and 26.59% at Site 3 (Table 5). The high IVI is caused by the large number of individuals found when compared to other species found in the research location.

Christella arida and *Drynaria quercifolia* had the lowest IVI at Site 1 with the same value of 5.18% (Table 5). *Drynaria quercifolia* is also the species that has the lowest IVI at Site 3 of 4.52% (Table 5). The lowest IVI at Site 2 is *Sphaerostephanos unitus* at 6.32% (Table 5).

Table 5. Important Value Index (IVI) (%) in Curug Gondoriyo Waterfall Region

No	Species	IVI (%)		
		St 1	**St 2**	**St 3**
1	*Athyrium asplenioides*	5,96	-	6,56
2	*Deparia japonica*	8,31	23,64	6,56
3	*Davallia denticulata*	5,96	6,94	13,94
4	*Davallia solida*	-	16,29	-
5	*Davallia trichomanoides*	-	-	11,08
6	*Hypolepis tenuifolia*	-	-	8,60
7	*Nephrolepis acutifolia*	-	-	6,15
8	*Drynaria quercifolia*	5,18	-	4,52
9	*Goniophlebium percussum*	-	-	6,15
10	*Microsorum scolopendria*	-	-	11,90
11	*Adiantum philippense*	21,80	57,45	26,59
12	*Pteris biaurita*	29,65	27,37	9,86
13	*Pteris ensiformis*	35,61	8,19	18,05
14	*Pteris vittata*	7,14	-	12,31
15	*Pteris wallichiana*	-	-	5,74
16	*Pityrogramma calomelanos*	10,67	21,05	20,47
17	*Tectaria dissecta*	15,45	9,74	-
18	*Tectaria slifolio*	-	8,81	-
19	*Christella arida*	5,18	-	13,09
20	*Christella dentata*	28,47	-	-

No	Species	IVI (%)		
		St 1	**St 2**	**St 3**
21	*Macrothelypteris torresiana*	20,63	7,25	11,05
22	*Sphaerostephanos heterocarpus*	-	6,94	-
23	*Sphaerostephanos unitus*	-	6,32	7,37

The high IVI of several types of ferns at each site indicates that these species are dominant and play a significant role in preserving the stability of the ecosystem. According to [4] high IVI is also influenced by favorable genetic traits and is also significantly influenced by how the environment, including the soil, climate, microbes, and competition with other species, interacts with the plant. This implies that plants that have a high adaptability can dominate in an area. A fern species with a low IVI value plays a minor ecological significance in the local ecosystem.

4 CONCLUSION

Overall, a total of 23 fern (Pteridophyta) species belonging to 8 families were recorded in the Curug Gondoriyo Waterfall area. The species composition was dominated by *Adiantum philippense*, with an abundance of approximately 72,000 individuals per hectare and the highest importance value index (IVI) of 57.45%. The family Pteridaceae was the most represented, comprising six species. The fern diversity index (H') ranged from 2.07 to 2.63, indicating a moderate level of diversity, while the evenness index (E) ranged from 0.83 to 0.91, suggesting that species were relatively evenly distributed across the study area. These findings highlight the ecological importance of the Curug Gondoriyo Waterfall as a habitat supporting diverse fern communities and provide essential baseline information for future conservation and management efforts in this ecotourism region.

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