

## Species Diversity of Pteridophytes in Watu Lumpang Waterfall, Grand Forest Park Raden Soerjo, East Java

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### Abstract

Currently, there is inadequate information on the distribution and diversity of pteridophytes in ecotourism destinations, even though they are an ecologically significant group in humid, shaded environments, such as waterfall regions. Therefore, this study aimed to list pteridophyte species and examine their taxonomic diversity, dominance, evenness, and Shannon–Wiener diversity index at the Watu Lumpang Waterfall. The line transect method was used at three observation stations (20 × 20 m), each separated into five 5 × 5 m plots, as part of a descriptive quantitative observational procedure. Morphological identification, individual counts, and environmental parameters (temperature, humidity, pH, and light intensity) were measured. Taxonomic diversity, Shannon–Wiener diversity ( $H'$ ), evenness ( $E$ ), and dominance ( $C$ ) indices were used to analyze the data. Dryopteridaceae was the most prevalent family among the 15 pteridophyte species, which were found in 7 families. Dominance was low ( $C < 0.3$ ), evenness was strong ( $E > 0.97$ ), and the Shannon–Wiener index ( $H' = 1.871$ ) showed moderate variety. Taxonomic Diversity was classified as poor ( $\Delta+ > 26.06$ ) at all locations. These results emphasize the potential of the Watu Lumpang Waterfall region as a significant habitat for pteridophyte conservation.

**Keywords:** Ecotourism; evenness index; fern community; species richness taxonomic diversity.

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## INTRODUCTION

Indonesia, specifically Java Island, is home to over 2,197 species of pteridophytes out of an estimated 10,000 worldwide. Java is estimated to have around 500 species of ferns, but the conservation status of this group of plants is not yet fully known, so further inventory of their diversity is still needed (Praptosuwiryo, 2013). Furthermore, a study conducted along the hiking trail of Mount Penanggungan in East Java recorded a total of 22 pteridophyte species from 13 families, distributed across different elevational zones (Hasyim et al., 2023).

Compound leaves or fronds with complex pinnate shapes are among the characteristics that distinguish pteridophytes from other fern groupings (Haufler et al., 2016). The circinate vernation of juvenile leaves is another characteristic that distinguishes it from other palms (Sofiyanti et al., 2021). Moreover, pteridophytes have uncertain development at the terminals of their stems and leaves (Vasco et al., 2013). Pteridophytes are characterized by the presence of well-structured xylem and phloem tissues arranged in diverse vascular architectures within the stem, a defining feature that has supported their ecological success over nearly 400 million years of evolution (Suissa & Friedman, 2022). Pteridophytes play significant ecological roles and can help preserve ecosystem balance. They are also widely distributed and diverse in nature.

Terrestrial and epiphytic ferns are the two general categories of pteridophytes, with a wide range of growth patterns and habitats. Non-parasitic plants, known as epiphytic pteridophytes, usually grow attached to their host trees, which could be trunks, branches, or cracks in the bark. Typically, pteridophytes and other epiphytic plants grow on oil palms and other host plants with rough bark (Sofiyanti, 2022). A moist environment, which terrestrial pteridophytes often encounter at the ground surface, is the main factor promoting the growth of most pteridophyte species, which are found in humid, tropical regions (Musriadi et al., 2017). Pteridophytes are predominantly found in forested mountain areas, where humidity, temperature, and elevation gradients create suitable microhabitats for their growth and distribution (Hasyim et al., 2023).

Additionally, waterfalls offer open spaces with ideal ecological conditions that sustain a diverse range of plant species, making them crucial fern habitats (Akbar et al., 2023). Gametophytes, which

require water for sexual reproduction, develop in high-humidity settings, making waterfalls ideal environments for growth (Farrar, 1967). They also provide pteridophytes with important moisture, particularly for species growing on rocky soils or cliffs adjacent to waterfalls (Nitta et al., 2020). Previous studies have shown a positive relationship between pteridophyte diversity and adequate water availability in waterfall settings (Windari et al., 2021).

Diverse patterns of pteridophyte diversity in waterfall environments have been documented in previous studies. In the Tretes Waterfall region of Jombang, Nuraini and Wisanti (2022) identified 37 pteridophyte species with moderate diversity. In Jurang Nganten region of Jepara Regency, 24 species from 19 taxa were recorded, indicating low-to-moderate diversity (Windari et al., 2021). *Adiantum cuneatum*, *Pteris vittata*, *Nephrolepis hirsutula*, and *Pityrogramma calomelanos* were among the 12 species from eight families were identified in the Gunung Geger Forest, Madiun Regency. Similarly, in the Tancak Waterfall region of Jember Regency (Suwila, 2015), Prastyo et al. (2015) identified 14 species from 10 families, with Polypodiaceae being the most abundant family. Collectively, these findings indicate that humid waterfall environments promote the growth of pteridophytes.

Ecological dynamics also shape the composition of pteridophyte species in waterfall settings. The waterfall area is a suitable habitat for fern growth, as demonstrated by a study in the Sekar Puduk Sari Waterfall Tourism Area, Wonosalam District, Jombang Regency, which recorded 28 species across 11 families at elevations ranging from 500 to 900 meters above sea level (Puspita & Wisanti, 2023). At the Kapas Biru Waterfall in Lumajang District, (Imaniar et al., 2017) recorded 30 species, 24 of which were members of Polypodiopsida. In the Girimanik Waterfall of the Wonogiri District, Kurniawati et al. (2016) identified 20 pteridophyte species, with Polypodiaceae being the most common. The 40-meter Watu Lumpang Cangar Waterfall, located within Tahura Raden Soerjo, is in a protected area. The waterfall sustains local flora and fauna while supporting the regional hydrological cycle (Aparecido et al., 2018). Furthermore, by linking highland forests, shrublands, and the waterfall zone, the area functions as an ecological corridor that facilitates the dispersal of plant and animal species.

Previous investigations of pteridophyte diversity in the broader Cangar area have produced limited coverage of the Watu Lumpang Waterfall. Research on fern spore characteristics in the TAHURA Raden Soerjo forest area of Cangar recorded five *Asplenium* species with distinct morphological traits, indicating a moderate level of pteridophyte diversity in this montane ecosystem (Pranita et al., 2017). Watu Lumpang Waterfall is ecologically distinctive because of its continuous mist, steep rock faces, and direct canopy openings – microhabitat characteristics that differ markedly from the surrounding forest floor conditions and have not been specifically examined in published pteridophyte studies. This gap justifies a targeted investigation of species composition, diversity patterns, and taxonomic structures at this locality.

## MATERIALS AND METHODS

An observational descriptive method was used in this study, which was conducted at the Watu Lumpang Waterfall tourism site in Cangar, situated at coordinates 7.6540° S and 112.6387° E within the Raden Soerjo Forest Park. Data were collected in January and February 2025. Three stations, each measuring 20 × 20 m, were established along a 75 m line transect, with quadrats placed purposively. Each station was further subdivided into five 5 × 5 m plots. The physical characteristics of pteridophytes, such as growth shape, rhizomes, leaves, and sori, were observed to identify them. The Diversity of pteridophytes from East Java (Efendi & Iswahyudi, 2019), the Flora of Malaya (Holtum et al., 2007), and the Diversity of pteridophytes in the R. Soeryo Forest Park were all cited in the identification procedure. All pteridophyte species at the study sites were identified and counted. Counters were used to determine the counts. Scientific categories (kingdom, phylum, class, order, family, genus, and species) were used to evaluate taxonomic diversity. In addition, the Shannon–Wiener diversity index, which describes species diversity in the community, the dominance index, which gauges the degree of dominance among pteridophyte species, and the evenness index, which quantifies the uniformity of species abundance, were calculated.

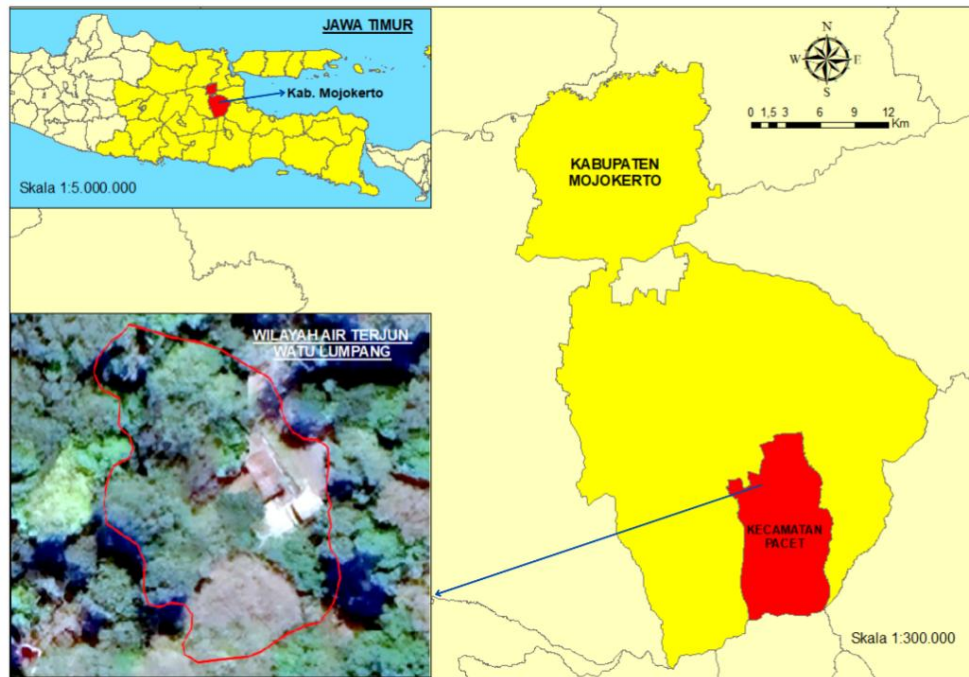


Figure 1. Sampling site located at Watu Lumpang Waterfall, Cangar, Raden Soerjo Forest Park, East Java, Indonesia.

Taxonomic index was calculated using the following formula:

$$\Delta + = [\sum_{i<j} \omega_{ij} x_i x_j] / [n(n-1)/2]$$

Explanation:

- $\Delta$  = Diversity of Taxa
- $ij$  = relationship between the two species.
- $\omega_1$  = A genus that contains distinct species
- $\omega_2$  = A family belonging to a distinct genus
- $\omega_4$  = Order and class
- $n$  = Total number of individuals.
- $x_i x_j$  = An indicator of species abundance.

Clarke and Warwick (1998) established the following standards for taxonomic diversity:

- $\Delta < 26.06$  = Diversity is classified as poor quality.
- $\Delta 26.06-69.07$  = Diversity is classified as moderate.
- $\Delta > 69.07$  = Diversity is classified as high.

In addition, Shannon-Wiener Diversity Index ( $H'$ ) was also calculated using the following formula:

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

Explanation:

- $H'$  = Diversity index.
- $S$  = Number of species discovered (Species Richness).
- $P_i$  = The  $i^{\text{th}}$  proportion ratio.
- $P_i = n_i / N$
- $n_i$  = Number of individuals of a specific species.
- $N$  = Total Number of individuals of all species in the sample.

Index of Shannon-Wiener were then categorized as the following:

- $H' < 1$  = Extremely low diversity; suggests that one or more species are dominant in the community.
- $1 \leq H' < 3$  = Moderate diversity; species vary, but some species continue to predominate.
- $H' \geq 3$  = High diversity; a more uniform distribution of species, suggesting that no species is noticeably dominant.

Index of plant dominance was calculated using the following formula:

$$C = \Sigma [n_i(n_i-1)] / [N(N-1)]$$

Explanation:

C = Simpsons' dominance index

$n_i$  = Number of individuals of the  $i^{\text{th}}$  species

N = Total Number of individuals of all species

The dominance index (C) ranged from 0 to 1. Values closer to 1 indicate high dominance by one or a few species (low diversity), whereas values closer to 0 indicate low dominance and a more even distribution of individuals among species (high diversity) (Simpson, 1949; Odum, 1993; Magurran, 2004).

Pielow's Evenness Index subsequently used to examine community stability using the following formula:

$$E = H'/\ln S$$

Explanation:

E = Evenness Index.

H' = Diversity Index.

S = Number of Species.

ln = Natural logarithm.

The equality index ranges from 0 to 1 which categorized as follows:

$0 < E \leq 0.4$  = marginal equality, marginalized group

$0.4 < E \leq 0.6$  = unstable community, moderate equality

$0.6 < E \leq 1.0$  = stable community, great evenness

## RESULTS

According to an inventory carried out at three sites, 15 pteridophyte species from seven families were found in the Watu Lumpang Waterfall Tourism Area in Cangar (Table 1). The families found were Dryopteridaceae, Polypodiaceae, Cyatheaceae, Aspleniaceae, Pteridaceae, Athyriaceae, and Davalliaceae. *Dryopteris filix-mas*, *Nephrolepis falcata*, *Polystichum persicifolium*, *Cyathea borneensis*, *Asplenium robustum*, and *A. salignum* were among the species observed at Station 1. *A. robustum*, *A. salignum*, *D. cycadina*, *Pteris sp.*, and *A. hispidulum* were found at Station 2. *Pteris sp.*, *A. salignum*, *D. dilatatum*, *Diplazium sp.*, *A. filix-femina*, *A. arcuatum*, *D. fejeensis*, *A. hispidulum*, *A. aristata*, and *P. persicifolium* were all found in Station 3. The Dryopteridaceae family was the most diverse, with four species, whereas only one species each represented the Polypodiaceae, Cyatheaceae, Aspleniaceae, Pteridaceae, and Davalliaceae families. The distribution of species differed between stations, and *A. salignum* and *A. hispidulum* were found at many locations.

**Table 1.** Inventory of pteridophytes in the Watu Lumpang waterfall tourist area

No.	Species Name	Family	Stations		
			1	2	3
1	<i>Dryopteris filix-mas</i> (L.) Schott	Dryopteridaceae	√		
2	<i>Nephrolepis falcate</i> (Sw.) Schott	Dryopteridaceae	√		
3	<i>Polypodium persicifolium</i> Desvaux	Polypodiaceae	√		√
4	<i>Cyathea borneensis</i> Copel	Cyatheaceae	√		
5	<i>Asplenium robustum</i> Blume	Aspleniaceae	√	√	
6	<i>Asplenium salignum</i> Blume		√	√	√
7	<i>Dryopteris cycadina</i> (Franch. & Sav.) Carl Christensen	Dryopteridaceae		√	
8	<i>Pteris sp.</i>	Pteridaceae		√	√
9	<i>Diplazium dilatatum</i> Blume	Athyriaceae			√
10	<i>Diplazium sp.</i>				√
11	<i>Athyrium filix-femina</i> (L.) Roth	Athyriaceae			√
12	<i>Athyrium arcuatum</i> Ching	Athyriaceae			√
13	<i>Davallia fejeensis</i> Hook	Davalliaceae			√
14	<i>Adiantum hispidulum</i> Swartz	Pteridaceae		√	√
15	<i>Arachnioides aristata</i> (G. Forst) Tindale	Dryopteridaceae			√

A terrestrial growth habit and compound leaves are characteristics of most pteridophytes in the Watu Lumpang Waterfall Tourism Area (Figure 2), whereas some species, such as *Polystichum persicifolium*, have simple leaves. In *A. salignum*, the sori are elongated, mostly spherical, and blackish brown, while in *P. persicifolium*, they can be round or orange. These morphological differences demonstrate the taxonomic and ecological diversity of pteridophytes in the area. A wide range of

adaptations to local climatic conditions, particularly humidity and light intensity, is suggested by the presence of both compound- and simple-leaved taxa, in addition to the different sorus types.



**Figure 2.** Pteridophyte species: A) *D. filix-mas*; B) *N. falcata* (Sw.) Schott; (C) *P. persicifolium* Desv.; D) *C. borneensis* Copel.; E) *A. robustum* Bl.; F) *A. salignum* Bl.; G) *D. cycadina*; H) *Pteris* sp.; I) *D. dilatatum* Bl.; J) *Diplazium* sp.; K) *A. filix-femina*; L) *A. arcuatum*; M) *D. fejeensis*; N) *A. hispidulum* Sw.; O) *A. aristata* (G. Forst.) Tindale.

Table 2 shows the results of the taxonomic diversity index computation for pteridophytes in the Watu Lumpang Waterfall Area. With indices of 2.220 and 2.480 at Station 2, and 2.570 at Stations 1, 2, and 3, respectively, the results were categorized as low. These results suggest that the species distribution at each station was inconsistent. A community's restricted phylogenetic breadth is typically reflected in low taxonomic diversity, indicating that the present species share comparable ecological niches and environmental preferences. This suggests that even with species diversity, the overall evolutionary diversity of the community remains limited, potentially making it more vulnerable to environmental changes.

**Table 2.** Taxonomic Diversity of Pteridophytes

Station	Diversity	Category
Station 1	2.220	Low
Station 2	2.480	Low
Station 3	2.570	Low

The Shannon–Wiener diversity index ( $H'$ ) values of the pteridophytes in the Watu Lumpang Waterfall Area are shown in Table 3. The Shannon index values recorded at each station were 1.781, 1.590, and 2.241, respectively. An overall index value of 1.868 was derived from pooled data across all sampling stations, reflecting the combined species diversity within the study area. With no species exhibiting ecological dominance, this number suggests that the community is comparatively balanced. An ecosystem with a moderate diversity index is said to have sufficient species diversity and evenness to be resilient and stable in the face of natural adversities. Moreover, the ecological value of the Watu Lumpang Waterfall Area is strengthened by the significant role this variety plays in sustaining ecological processes, including nutrient cycling, microclimate regulation, and habitat provision for associated species to thrive.

**Table 3.** Pteridophytes diversity index

No	Species Name	Number of Individuals	ni/N	Ln ni/N	H' (ni/N. Ln ni/N)
STATION 1					
1	<i>Dryopteris filix-mas</i> (L.) Schott	45	0.118	-2.132	0.253
2	<i>Nephrolepis falcata</i> (Sw.) Schott	60	0.158	-1.846	0.291
3	<i>Polypodium persicifolium</i> Desv	51	0.134	-2.008	0.269
4	<i>Cyathea borneensis</i> Copel	42	0.111	-2.203	0.244

No	Species Name	Number of Individuals	ni/N	Ln ni/N	H' (ni/N. Ln ni/N)
5	<i>Asplenium robustum</i> Bl.	57	0.150	-1.897	0.285
6	<i>Asplenium salignum</i> Bl.	63	0.166	-1.798	0.298
<b>TOTAL STATION 1</b>		318	1.000	-	<b>1.781</b>
<b>STATION 2</b>					
1	<i>Asplenium robustum</i> Bl.	75	0.263	-1.335	0.351
2	<i>Asplenium salignum</i> Bl.	85	0.298	-1.209	0.361
3	<i>Dryopteris cycadina</i> (Franch.&Sav.) C.Chr.	54	0.189	-1.661	0.315
4	<i>Pteris</i> sp.	75	0.263	-1.335	0.351
5	<i>Adiantum hispidulum</i> Sw.	51	0.179	-1.721	0.308
<b>TOTAL STATION 2</b>		340	1.000	-	<b>1.590</b>
<b>STATION 3</b>					
1	<i>Polypodium persicifolium</i> Desv	80	0.129	-2.047	0.264
2	<i>Asplenium salignum</i> Bl.	110	0.177	-1.729	0.307
3	<i>Pteris</i> sp.	90	0.145	-1.929	0.280
4	<i>Diplazium dilatatum</i> Bl.	62	0.100	-2.303	0.230
5	<i>Diplazium</i> sp.	40	0.065	-2.741	0.177
6	<i>Athyrium filix-femina</i> (L.) Roth	45	0.073	-2.621	0.190
7	<i>Athyrium arcuatum</i> Ching	42	0.068	-2.693	0.182
8	<i>Davallia Fejeensis</i> Hook	47	0.076	-2.577	0.195
9	<i>Adiantum hispidulum</i> Sw.	75	0.121	-2.112	0.256
10	<i>Arachnioides aristata</i> (G. Forst) Tindale	47	0.076	-2.577	0.195
<b>TOTAL STATION 3</b>		638	1.000	-	<b>2.242</b>
<b>GRAND TOTAL</b>					<b>1.871</b>

The pteridophyte dominance and evenness index values of the three observation stations in the Watu Lumpang Waterfall Area are shown in Table 4. With scores of 0.170 at Station 1, 0.208 at Station 2, and 0.113 at Station 3, the dominance index values were low, suggesting that no species had considerable ecological dominance. The evenness index values at Station 1, 2, and 3 were categorized as stable. A generally regular distribution of individuals across species was reflected by high evenness, indicating a well-balanced community structure in the study region. These results showed the ecological stability of the pteridophyte community, the absence of resource monopolization, and the ability of species to coexist in favorable environmental conditions.

**Table 4.** Dominance index and species evenness index for each station

Station	Dominance	Category	Evenness	Category
Station 1	0.170	Low	0.994	Stable
Station 2	0.208	Low	0.988	Stable
Station 3	0.113	Low	0.974	Stable

## DISCUSSION

It was discovered that 15 species of Pteridophytes, representing 7 families, Polypodiaceae, Dryopteridaceae, Cyatheaceae, Aspleniaceae, Pteridaceae, Athyriaceae, and Davalliaceae were present in the Watu Lumpang Waterfall Tourist Area. Station 3 had the highest number of species (10), followed by Stations 1 and 2 with 6 and 5 species, respectively. The pteridophyte taxonomic diversity in the study area was poor. In addition, with taxonomic diversity values of 2.220, 2.480, and 2.570 at Stations 1, 2, and 3, respectively, the species distribution was reasonably diverse but was dominated by closely related taxa. Lower taxonomic diversity showed tighter evolutionary links among species, whereas higher numbers suggested greater variety in a group, as shown by Clarke and Warwick (1998). The ecological circumstances of the Watu Lumpang Waterfall Area corroborated the taxonomic diversity index findings.

The study area's moderate variety was indicated by the Shannon–Wiener diversity index (H') of 1.8. Musriadi et al. (2017) reported that the Pocut Meurah Intan Tahura Area had a diversity range of 1.5–3.0, which is consistent with this conclusion. Species diversity within a community is maintained through various mechanisms of coexistence, including interspecific interactions and niche differentiation that allow species with varying adaptive capacities to persist together (Chesson, 2000). Strong (2016) observed that moderate H' values reflect a relatively balanced distribution of species abundance. Furthermore, habitat stability, species abundance, and population size are important determinants of the moderate diversity index (Kiester, 2013).

Dominance index values were low at all three stations ( $C = 0.170, 0.208,$  and  $0.113$  at Stations 1, 2, and 3, respectively). Musriadi et al. (2017) observed that low dominance values characterize plant communities in which no single species exerts a disproportionate ecological influence. The evenness index values for Stations 1, 2, and 3 were  $0.994, 0.988,$  and  $0.974,$  respectively, all of which fell in the high evenness category. Hutasuhut and Febriani (2019) noted that evenness values approaching 1 indicate the absence of species dominance in habitats supporting uniform growth.

Both terrestrial and epiphytic pteridophytes were found at the Watu Lumpang Waterfall. Twelve terrestrial and three epiphytic species were recorded, with the terrestrial species displaying greater richness. This pattern aligns with the findings of Nurchayati (2016), who showed that terrestrial pteridophytes are typically more diverse than epiphytes in high-humidity, moderate-temperature waterfall environments. Among the epiphytes, *Asplenium salignum* was the most abundant, with 258 individuals recorded at all three stations. Due to its strong altitude adaptation, this species is regarded as a dominant epiphytic fern across various forest types and microclimatic conditions (Khamalia, 2018).

The greatest number of species (4) was found in the Dryopteridaceae family. Owing to their great adaptability to a wide range of ecological conditions including open environments with bright light, fluctuating humidity, and variable temperatures certain fern families have achieved remarkable species richness across diverse global habitats (Anderson, 2021). The genus *Dryopteris*, represented by species such as *D. filix-mas* and *D. cycadina*, is among the largest genera in the family Dryopteridaceae, with approximately 400 species distributed worldwide and its greatest diversity concentrated in temperate and tropical regions of East Asia (Zuo et al., 2022). *Asplenium salignum* was the most abundant species overall, with 258 individuals across all stations, consistent with the widely documented tolerance of the genus to diverse habitats, from lowlands to montane zones (Schneider et al., 2017).

The differences in species composition between Station 1 and the remaining stations likely reflect elevational gradients that drive variation in temperature, humidity, and light intensity, which are known to shape fern species distribution and richness (Watkins et al., 2006). Substrate availability and environmental gradients have been identified as important drivers of pteridophyte species turnover (Kessler and Siorak, 2007). The measured environmental parameters were consistent across all stations: pH = 7 (neutral), relative humidity 70–85%, temperature 20–26°C, and light intensity 930–1,856 lx. The proximity of Stations 2 and 3 to the spray zone of the waterfall may account for the higher species richness observed there, as enhanced moisture availability has been shown to promote pteridophyte diversity in comparable settings (Windari et al., 2021).

The pteridophyte assemblage at the Watu Lumpang Waterfall has both ecological and ethnobotanical significance. Ethnobotanical surveys have documented the medicinal uses of *Nephrolepis* species in several Indonesian communities (Muhammad et al., 2020), and pteridophyte diversity has been linked to important ecosystem services, including erosion control, water regulation, and microhabitat provision (Sharpe et al., 2010). The data generated in this study provide a baseline for monitoring biodiversity changes and evidence-based management of this ecotourism site.

## CONCLUSION

Fifteen pteridophyte species from seven families were recorded at the Watu Lumpang Waterfall Tourism Area, Cangar. Taxonomic Diversity was poor at all three stations. The low dominance and high evenness index values indicated that individual abundances were uniformly distributed across species, with no single species numerically controlling the community. The mean Shannon–Wiener index ( $H' = 1.871$ ) reflected moderate species diversity. These findings establish the first inventory baseline for pteridophyte diversity at this site and highlight its potential value for conservation within the Tahura Raden Soerjo management framework.

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## CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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