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Pteridophytes Diversity and Distribution Along The Elevational Gradient of Mount Penanggungan's Hiking Trail, East Java, Indonesia

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Abstract. *Pteridophytes (ferns) are a fundamental element of tropical rainforests, which provide excellent microhabitats for their development. In addition, the sensitivity of pteridophytes to shifts in microclimate and anthropogenic disturbances makes them excellent environmental bioindicators. The purpose of this study was to determine the diversity and distribution of pteridophytes along the elevational gradient of two well-known hiking trails of Mount Penanggungan, East Java, Indonesia. Using a 10x10 m² plot and transect line, we examined the composition, species diversity using Shannon-Wiener diversity index (H'), relative abundance, and distribution pattern using Morisita index of dispersion (Id) of ferns along an elevational gradient (700–1500 m above sea level) on the hiking trails of Mount Penanggungan, i.e., Tamiajeng and Kunjorowesi. As many as 14 species from 7 families living in both terrestrial and arboreal types were identified. Species composition along the elevation gradient revealed a pattern of predominating species. The Shannon-Wiener diversity index (H') indicated a moderate level of diversity, where many pteridophytes species are found on the altitude gradient between (700-900 m dpl), and the Morisita index of dispersion (Id) indicated a clustered distribution pattern for most of the species. This pattern of diversity and distribution can be explained by changes in biotic and abiotic factors.*

Keywords: *community ecology, fern, plant distribution, plant diversity.*

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INTRODUCTION

Indonesia is one of the largest archipelagic nations, having a wide variety of landscapes and biodiversity. Ferns (pteridophytes), a cryptogam or non-seed-bearing plant, play a vital role in Indonesia's ecosystem, where over 2000 species of ferns from 40 families have been documented (Hassler, 2022). This enormous fern diversity is primarily the result of Indonesia's vast continental area, climate, geography, and island endemics (de la Rosa-Manzano et al., 2019; Wang et al., 2016). As one of the centers of plant diversity in Southeast Asia, scientific research should emphasize the study of fern diversity.

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Research on the diversity of ferns in Java has been widely reported in various regions, e.g., West Java: Gunung Halimun Salak National Park (Ariyanti et al. 2011), Cibodas Botanical Garden (Nasution, 2015), and Gunung Gede Pangrango National Park (Fatahillah et al., 2018); Central Java: Gunung Selamet, Baturaden (Widhiastuti, 2006), Gunung Merbabu National Park (Astuti et al., 2018), Pekalongan Regency (Lestari et al., 2019), and Penggaron Forest, Semarang (Abadiyah et al., 2019); East Java: TAHURA Ronggo Soeryo, Cangar (Romaidi et al., 2012), Alas Purwo National Park (Ridianingsih et al., 2017), and Sumber Nyolo, Malang (Suriansyah et al., 2022). However, there is a research gap on the inventory and distribution of ferns in Java (Hasanah et al., 2021).

Ferns are great tools for distinguishing the elevational gradient of tropical mountains (Frahm & Gradstein, 1991), due to the following reason: they can be found on soil substrate or attached to trees or rotting wood, they are indicators of environmental parameters like temperature and humidity, they have significantly larger ranges than the majority of vascular plants, and they have fewer species than other vascular plants. Nonetheless, anthropogenic disturbances, such as the conversion of natural habitats to mass ecotourism attractions (e.g., hiking) (Septiadi et al., 2018) have led to a decline in biodiversity. Ferns (Pteridophyta) as part of biodiversity are communities that have important ecological functions in tropical forest ecosystems, e.g., in forest ground, they provide litter mixtures for the formation of soil nutrients; whereas in forest canopies, epiphytic ferns often represent some of the most abundant taxa (Gonzalez et al., 2017), providing nutrient for many organisms. Finally, understanding the impact of anthropogenic disturbance on ferns diversity along the elevational gradients has been extensively studied in other regions (Oseguera-Olalde et al., 2022; Guzmán-Jacob, et al. 2020; Carvajal-Hernández et al., 2018) but remain a major challenge for Indonesian tropical forest, where the knowledge of disturbance impact on these essential habitats for ferns has yet to be conclusive.

Since such studies of fern diversity in natural areas with a high level of human disturbance are lacking, we aimed to investigate the composition, species diversity, relative abundance, and distribution pattern of pteridophytes along the elevational gradient of Mount Penanggungan's hiking trails, East Java, Indonesia.

MATERIALS AND METHODS

Study Area

Mount Penanggungan (-7.615282919249491, 112.62024504701455) is one of the inactive volcanoes in East Java province, located between the Mojokerto and Pasuruan regencies at an elevation of 1653 meters above sea level (m asl). It is a well-known tourist attraction for hiking and camping, and it has been designated a Provincial Cultural Conservation Area (Pratiknyo, 2016) due to the historical Mataram Kingdom and Majapahit Kingdom relics (Paripurno et al., 2018). Mount Penanggungan's natural conditions may sustain a wide population of fern. This is proven by the natural condition of the vegetation on the slopes of Mount Penanggungan, which consists of mosses, ferns, and higher plant groups such as angiosperms and gymnosperms. For this research, two famous Tamiajeng and Kunjorowesi hiking trails were chosen for study.

Sampling and Study Material

The research was conducted along Mount Penanggungan's, i.e., Tamiajeng (on

the south) and Kunjorowesi (on the north) hiking trails from November 2022–January 2023. For each hiking trail (hereafter transect lines), five sampling points were selected based on the elevational difference at 200-meter intervals (range from 700, 900, 1100, 1300, and 1500 m asl; Figure 1).

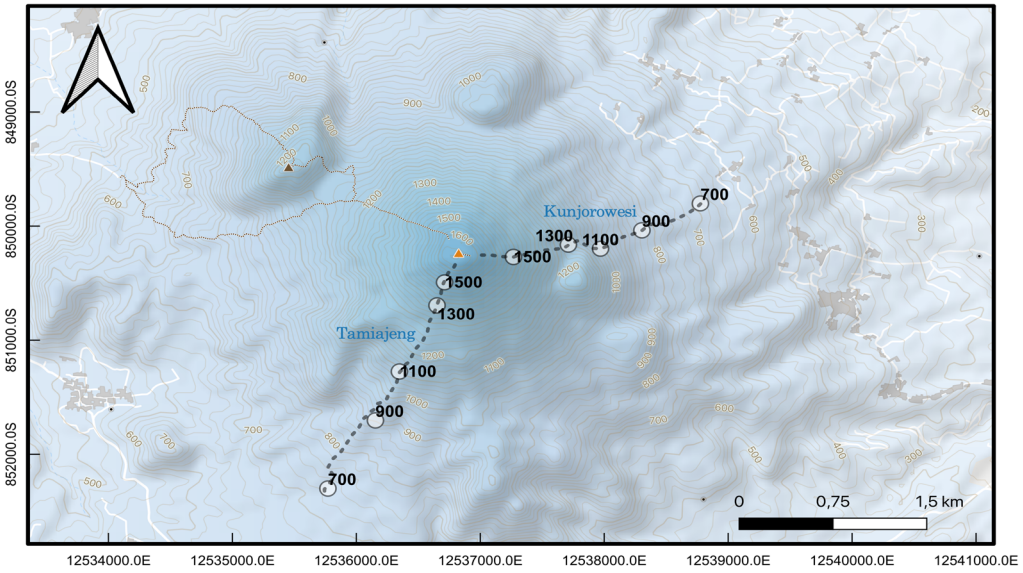

Figure 1. Sampling points of ferns based on elevational gradient along the hiking trails on Mount Penanggungan

By following Ariyanti & Sulistijorini (2011), our sampling was based on a primary plot of 10x10 m2, parallel to the transect line (Figure 2). Sampling for terrestrial ferns and arboreal ferns was conducted differently. In order to collect samples of terrestrial ferns, five primary plots were established along the 50 m transect lines on the right and left sides, and subplots of 1x1 m2 were placed inside the 10x10 m2 plots (Figure 2A). For arboreal ferns, 8 plots of 10x10 m2 were established along the 40 m transect lines on the right and left sides, where eight trees (diameter >20 cm) with attached ferns observed (Figure 2B).

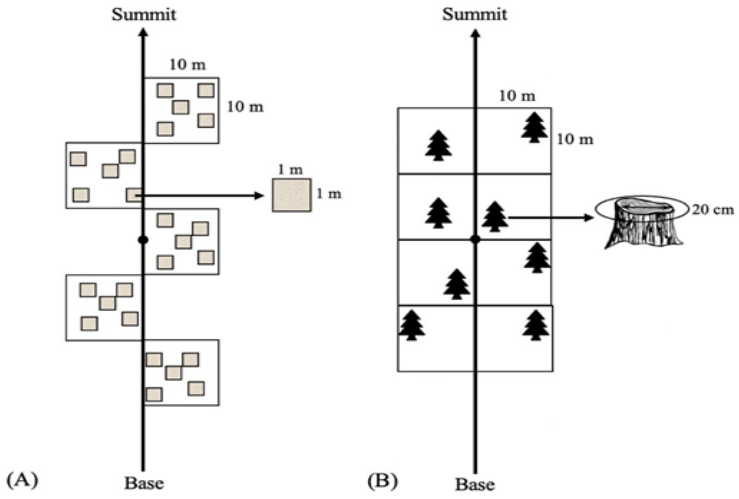

Figure 2. Design of plot for sampling of terrestrial ferns (A) and arboreal ferns (B) along the hiking trails in Mount Penanggungan.

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Individuals were counted based on the number of individuals. The voucher specimens were collected in a paper/plastic bag where the collection number was assigned. Information was also collected for abiotic parameters (temperature, humidity).

The characteristics of species (morphology, color, thallus form, and sporophyte shape, etc.) were documented with a macro lens (10–20x magnification) to aid in species classification. The taxa were identified up to the genus and species level. We relied on the identification book, e.g., Jenis Paku Indonesia (Sastrapradja et al., 1980); A classification for extant ferns (Smith et al., 2006); and Ferns of the Malaysian Rainforest: A journey through the fern world (Yusuf, 2010).

Data analysis

The data analyses include species composition, relative abundance along the elevational gradient (for each hiking trail), was analyzed using the following ecological indek Shannon-Wiener diversity index (H'), and distribution pattern using the Morisita index of dispersion (Id). Shannon-Wiener diversity index (H'), we used the formula as follows (Odum, 1994):

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

Where *s* is the number of species, ni depicts the total individual of species-i, and N depicts the total individual of all species. Based on Fachrul (2007), the categorization falls into (i) H' > 3, high diversity; (ii) 1 ≤ H' ≤ 3, moderate diversity; (iii) H' < 1, low diversity. To investigate the significant difference among hiking trails, we used Hutcheson t-tests (Hutcheson, 1970).

For the Morisita index of dispersion (Id), we used the formula as follows (Odum, 1994):

$$I_d = n \frac{\sum X^2 - N}{N(N-1)}$$

Where *n* depicts the number of plots, N depicts total individuals on plot, ∑x depicts total individual of species-*i*, and ∑x² depicts the quadratic number of total individuals of species-*i* on plot. To confirm the results, we used Chi-square test, using the formula as follows (Brower & Zar, 1989):

$$x^2 = (n \sum X^2 / N) - N$$

where x² depicts Chi-square (Xcalc.), n depicts total of plot, ∑*Xi*² depicts the total individual on primary plot, and *N* depicts total individuals. Subsequently, the $X_{calc.}$ were compared to Xtabl. using degree of freedom (df = n-1) with α = 0.05 for the significancy of test.

RESULTS AND DISCUSSION

Our investigation revealed 14 fern species (12 species were identified to species level, 2 species were identified to genus level) from 7 families. As many as 6 species were found in the Tamiajeng trail; the largest population of individuals was *Pityrogramma calomelanos* (38 individuals); the lowest was Deparia petersenii (2 individuals). As many as 12 species were found in Kunjorowesi trail; the highest number of individuals was *Cyathea contaminans* (33 individuals); the lowest was *Nephrolepis* sp. (1 individual). The overall relative frequency (in percentage) showed that *Pityrogramma calomelanos* was the highest species to be encountered (22.8%), followed by *Cyathea contaminans* (18.4%), and *Pityrogramma* (12.8%). The summary list of fern species, number of individuals, and relative frequency is shown in Table 1.

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Table 1. List of fern species found on hiking trails of Mount Penanggungan. Table entries include family, species, total number of individuals on each hiking trails (T = Tamiajeng, K = Kunjorowesi), and overall relative frequency in percentage for each species (F, %)

Family	Species	*n*		F (%)
		T	K	
Pteridaceae	*Adiantum concinnum* Humb. & Bonpl. ex Willd.	-	22	8.8
	Adiantum cuneantum Langsd. & Fisch.	11	-	4
	Adiantum peruvianum Klotzsch.	-	4	1.6
	Adiantum tenerum Sw.	-	8	3.2
	Pityrogramma calomelanos (L.) Link	38	19	22.8
	Pityrogramma sp.	32	-	12.8
Cyatheaceae	*Cyathea contaminans* (Wall. ex Hook.) Copel.	13	33	18.4
Athyriaceae	*Deparia petersenii* (Kunze) M.Kato.	2	4	2.4
	Diplazium esculentum (Retz.) Swartz	-	28	11.2
Lygodiaceae	*Lygodium japonicum* (Thunb.) Sw.	17	9	10.4
	Lygodium microphyllum (Cav.) R.Br.	-	2	0.8
Marcileaceae	*Marsilea crenata* C. Presl	-	2	0.8
Lamoriopsidaceae	*Nephrolepis* sp.	-	1	0.4
Dennstaedtiaceae	*Pteridium aquilinum* (L.) Kuhn.	-	5	2

Based on the elevational gradient, our results revealed a pattern of fern indicated by relative abundance. For instance, Cyathea contaminant can only be found at a high elevation of 1500 m asl, on both hiking trails. In contrast, P*ityrogramma calomelanos* can be found in both hiking trails on wide-range elevations (700–1300 m asl). *Pteridium aquilinum* can only be found at high elevation of 1300 m asl, only on Kunjorowesi trail; several species at elevation of 700–1100 m asl can also be found only on Kunjorowesi trail, i.e., *Adiantum concinnum*, *Adiantum peruvianum*, *Adiantum tenerum*, *Diplazium esculentum*, *Lygodium microphyllum*, *Marsilea crenata*, and *Nephrolepis* sp. The *Pityrogramma* sp. can only be found on Tamiajeng trail at an elevation of 700–1300 m asl; also similar to *Adiantum cuneantum* which can be found at elevation of 700–900 m asl, and *Adiantum cuneantum* which can be found at an elevation of 700–900 m asl. The summary of the relative abundance of fern species along the elevational gradient is shown in Figure 3.

Based on the diversity index and Hutcheson *t*-tests (Table 2), it was revealed that Kunjorowesi (H' = 2.066) had a higher diversity index than those in Tamiajeng (H' =1.557, df = 247, $p = \leq 0.05$); most hiking trail sites showed moderate diversity index (H' = 1–3).

The Morisita Index of dispersion (Id) of ferns differed among the two hiking trails on Mount Penanggungan (Table 3). Tamiajeng trails had a Morisita index (Id) value between 12.0–113.8 and a clustered distribution pattern; Kunjorowesi trails had a Morisita index (Id) value between 10.31 – ~ and a clustered and uniform distribution pattern. All species of ferns shared the clustered distribution pattern, except for *Nephrolepis* sp. which reveals a uniform distribution pattern. The summary of the distributional pattern of fern species between hiking trails on Mount Penanggungan is shown in Table 2.

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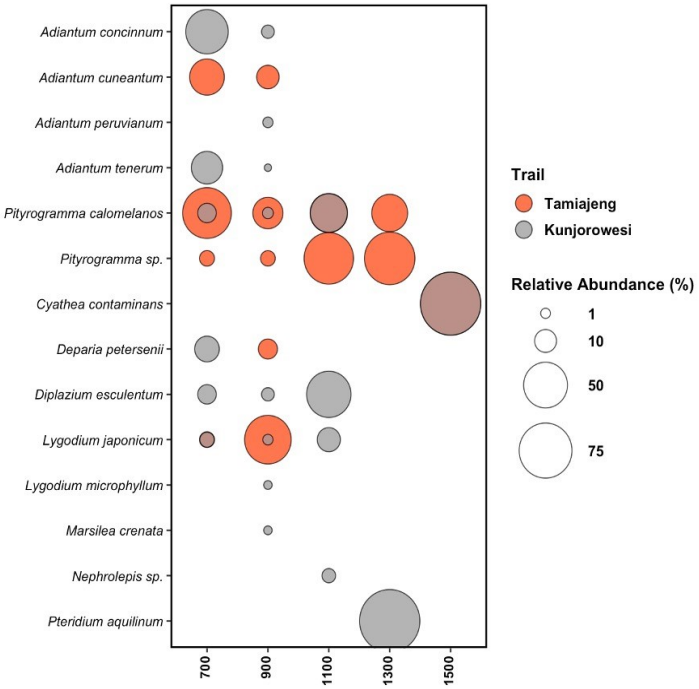

Figure 3. Relative abundance (in percentage) of fern individuals on hiking trails of Mount Penanggungan.

Table 2. Distributional patterns (Id) of fern species between trail sites on Mount Penanggungan

Trail	Species	Id	$X_{calc.}$	$X_{tabl.}$	Dist. Pattern
	Pityrogramma sp.	12.0	389.9	66.3	Clustered
	Pityrogramma callomelanos	113.8	433.1	66.3	Clustered
Tamiajeng	*Lygodium japonicum*	14.7	268.3	66.3	Clustered
	Deparia petersenii	50.0	98.0	66.3	Clustered
	Adiantum cuneatum	33.6	375.4	66.3	Clustered
	Cyathea contaminans	19.2	267.8	66.3	Clustered
	Diplazium esculentum	10.8	314.9	66.3	Clustered
	Cyathea sp.	15.5	309.9	66.3	Clustered
Kunjorowesi	*Adiantum coccinnum*	16.2	368.9	66.3	Clustered
	Deparia petersenii	16.7	96.0	66.3	Clustered
	Adiantum peruvianum	50.0	196.0	66.3	Clustered
	Nephrolepis sp.	~	49.0	66.3	Uniform
	Adiantum tenerum	28.6	242.0	66.3	Clustered
	Marsilea crenata	50.0	98.0	66.3	Clustered
	Lygodium japonicum	13.9	152.1	66.3	Clustered
	Pteridium aquillarium	30.0	165.0	66.3	Clustered
	Lygodium microphyllum	50.0	98.0	66.3	Clustered
	Cyathea contaminans	10.3	347.3	66.3	Clustered

Based on the diversity index, the Kunjorowesi trail has a higher diversity index of 2.06 compared to the Tamiajeng trail of 1.56, which is thought to be caused by differences in vegetation, biotic and abiotic factors, and human disturbance. The area along the Kunjorowesi trail has a denser canopy than the Tamiajeng trail, providing optimal conditions (e.g., microclimatic conditions, humidity, availability of resources) for a diversity of ferns to develop, in line with Hoshizaki & Moran (2001) where the nails can grow optimally in the temperature range of 21-27˚C. Appropriate temperature conditions lead to the distribution of many ferns in tropical forest areas. Open space is seen more frequently on the Tamiajeng trail than on the Kunjorowesi trail, resulting in drier conditions, disturbed soils, and a limited number of host tree species, which could not provide favorable and optimal conditions for the fern community. In addition, the increase in hiking activity on the Tamiajeng trail (the most popular hiking route on Mount Penanggungan) can disrupt their natural ecosystem.

Species number and relative abundance varied with altitude (Figure 3); the higher the altitude, the rarer the species. According to Surfiana et al. (2018), an increase in altitude induces changes in environmental factors, such as temperature, pH, light intensity, and humidity, such that the number and varieties of ferns that can be found may vary. This is further corroborated by the findings of Astuti et al. (2018) who determined that variances in altitude can influence changes in the region's environmental parameters. Some species can be found in a wide range of elevations, e.g., *Pityrogramma callomelanos*, which was frequently found in the elevation of 700–1300 m asl, open areas, and the hill slope of the mountain. In agreement with previous studies (Afrianto et al., 2016), this species' elevational occurrence is wide and can be found abundantly in open areas and hill slopes. Based on our results, some species can only be found at certain elevations, i.e., *Cyathea contaminans* (1500 m asl), which was mostly found near the water bodies of the forest edge, which was similar to Hanum et al. (2014) findings. However, Ong (2003) mentioned that this species is frequently encountered on a wide range elevation (200–1600 m asl) along hiking trails, forest edges, and open areas, where the light intensity is optimum. There will eventually be fewer ferns as elevation increases, which can be explained by variations in ecological conditions and human disturbances (Susila et al. 2020). In addition, Astuti et al. (2018) stated that increasing elevation will be associated with changes in environmental parameters, therefore only ferns able to adapt to environmental changes can survive.

Except for *Nephrolepis* sp., the majority of fern species exhibited a clustered distribution pattern, which can be explained by the difference in biotic and abiotic conditions. The dispersal of fern spores may contribute to the concentration of these species. Moreover, abiotic factors such as temperature, humidity, and light intensity have a significant impact on the distribution pattern of ferns. Therefore, the clustered distribution pattern represents the presence of individuals in certain locations that raise the possibility of the formation of new groups of the same population in neighboring regions.

CONCLUSION

It can be concluded that the distribution of pteridophytes communities on the hiking trails of Mount Penanggungan varied according to trails and elevational gradient. Due to differences in vegetation, biotic and abiotic conditions, and human disturbances, the spe-

cies variety on the Kunjorowesi trail was significantly higher than that of the Tamiajeng trail.

AUTHOR CONTRIBUTION

M.A.H. designed and supervised all of the research and also wrote the manuscript; B.F.H. and L.S. analyzed the data; F.F., Y.S., R.M.M., C.R.A., M.N.I.H. collected samples from the station and analyzed in the laboratory.

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CONFLICT OF INTEREST

The authors declare in writing this article there is no conflict of interest.

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