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Diversity of *pteridophyte* species as bioindicators of forest ecosystem quality in Taman Hutan Raya Raden Soerjo Batu, East Java

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ABSTRACT. *Pteridophyte* diversity is used as a bioindicator of ecosystem quality due to its sensitivity to environmental changes. This research aims to analyze the diversity and distribution of *pteridophytes* in three types of forest vegetation namely closed forest, open forest, and post-fire forest, in Tahura Raden Soerjo, Batu, East Java. The research employed a transect line and plot survey method to collect data on species composition, ecological indices and observed environmental parameters. Community structure was analyzed using the Shannon–Wiener diversity index, Pielou's evenness index, and Simpson's dominance index. The relationship between species and environmental parameters was analyzed using Canonical Correspondence Analysis (CCA) and Pearson's correlation test, with a focus on light intensity, temperature, humidity, and soil pH. The results showed that the highest species diversity was found in closed forests, supported by stable microclimate conditions, high humidity, and low light intensity. The most abundant and widely distributed species in this vegetation type was *Dryopteris adnata*. In open forests, diversity was in the moderate to high category, with commonly found species such as *Dryopteris wallichiana*. Post-fire vegetation showed the lowest diversity and was dominated by disturbance-tolerant species such as *Selliguea enervis*. This research confirms the potential of *pteridophytes* as effective bioindicators for assessing the health of forest ecosystems. It supports their use in conservation strategies and the achievement of SDG 15 (Life on Land).

Keywords: bioindicator; canonical correspondence analysis; forest ecosystem; pteridophyte diversity; vegetation types

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INTRODUCTION

Pteridophyte or ferns are plants with a wide distribution and high diversity. It is estimated there are between 10,000 and 12,000 distinct *pteridophyte* species distributed across the world (Luckita *et al*., 2021). Indonesia as a country with a high level of biodiversity has 1300 species of total diversity in the world (Imaniar *et al*., 2017). On Java Island, *pteridophyte* diversity shows significant variation between provinces. Research by Atho *et al*. (2020) stated that there were 450 species in West Java, 333 species in Central Java, and 319 species in East Java. East Java is dominated by the genera *Pteris* and *Adiantum* from the family Pteridaceae which is the dominant family because it can adapt to tropical and subtropic climates (Lestari & Adjie, 2020).

Morphological characteristics of *pteridophyte* include the circinate vernation of the tip of young leaves and the presence of sorus on the lower surface of the lamina (Yatskievych, 2003). The habitat of *pteridophyte* in forest ecosystems is very diverse, including terrestrial, epiphytic, and some aquatic species (Sianturi, 2020). The selection and interpretation of diagnostic characters followed the updated classification framework of the Pteridophyte Phylogeny Group I (Schuettpelz *et al*., 2016), which promotes a more phylogenetically informed and globally standardized approach to fern taxonomy.

The ecological roles of *pteridophyte* in forest ecosystems include contributions to nutrient cycling, provision of microhabitats for other organisms, and participation in understory vegetation structure (Brock *et al*., 2016). These unique characteristics and ecological roles make *pteridophyte* a candidate bioindicator of forest ecosystem quality (Silva *et al*., 2018). Characteristics that make *pteridophyte* effective bioindicators include high sensitivity to environmental change and wide distribution (Banaticla & Buot, 2005). Some *pteridophyte* species even can accumulate pollutants, so the presence or absence of certain species can provide valuable information about the level of pollution in an area (Samecka-Cymerman *et al*., 2009). *Pteridophyte* have long been recognized as a group of plants that have great potential as bioindicators of forest environmental quality (Dai *et al*., 2020).

Previous studies have shown a high correlation between *pteridophyte* diversity and various physical parameters of the environment. The distribution and diversity of *pteridophyte* are highly affected by abiotic factors such as humidity, temperature, soil pH, altitude, and light intensity (Nugraheni & Prabowo, 2022). The majority of *pteridophyte* grow optimally in high humidity conditions with sufficient water availability, with ideal air humidity ranging from 64-85% *(Savira et al*., 2021). Elevation of *pteridophyte* growth in the mountains can be found at altitudes between 1200-1400 meters above sea level (Khairunisa & Wisanti, 2023), with optimal temperatures ranging from 21-27°C (Hasanah, 2020). Light intensity suitable for pteridophyte growth ranges from 500-2152 lux (Ridianingsih *et al*., 2017), with optimal soil pH for *pteridophyte* growth in the range of 5.5-6.5 (Astuti *et al*., 2018). This high correlation between environmental physics parameters and *pteridophyte* diversity and distribution reinforces the potential of using *pteridophyte* as sensitive and effective bioindicators of forest ecosystem quality.

Although ecological studies on ferns in Java have advanced in recent years, significant taxonomic gaps remain in several species groups particularly within the genera *Thelypteris*, *Dryopteris*, and *Diplazium*, which often exhibit overlapping morphological characters and have not been extensively investigated using molecular approaches. This taxonomic ambiguity hinders accurate species-level identification and complicates the compilation of species checklists and distribution mapping. Schuettpelz *et al*. (2016), through the Pteridophyte Phylogeny Group I (PPG I), emphasized the importance of incorporating phylogenetic methods and adopting a standardized global classification system, which has yet to be fully applied in tropical regions such as Indonesia.

This research aims to analyze the diversity of *pteridophyte* in Taman Hutan Raya Raden Soerjo, Pasinan Area as well as their potential as bioindicators of environmental quality. This area faces the threat of degradation due to natural factors and human activities, so this research focuses on three vegetation types: closed forest, open forest, and post-fire forest. The results of the research in the form of *pteridophyte* diversity can be useful for providing an overview of ecosystem conditions in each vegetation type, finding species that are sensitive to environmental changes, and supporting more sustainable forest management. Analysis of the relationship between species and environmental parameters is expected to reveal the role of *pteridophyte* as bioindicators of forest ecosystems, support conservation strategies, and provide accurate and sustainable monitoring methods (Karger *et al*., 2011).

MATERIALS AND METHODS

Study area. This research was conducted in the Taman Hutan Raya (Tahura) Raden Soerjo Pasinan Area Sumber Brantas Village. Sumber Brantas Village is a village located in the southwest area of the slopes of Mount Arjuno which is a highland area with an altitude of approximately 1400-1700 meters above sea level. Data collection was carried out on three types of vegetation, closed forest vegetation (7°44'47.66"S 112°32'25.81"E), open forest vegetation (7°44'47.47"S 112°32'45.68"E), post-fire forest vegetation (112°32'45.68"E, 112°32'47.80" E).

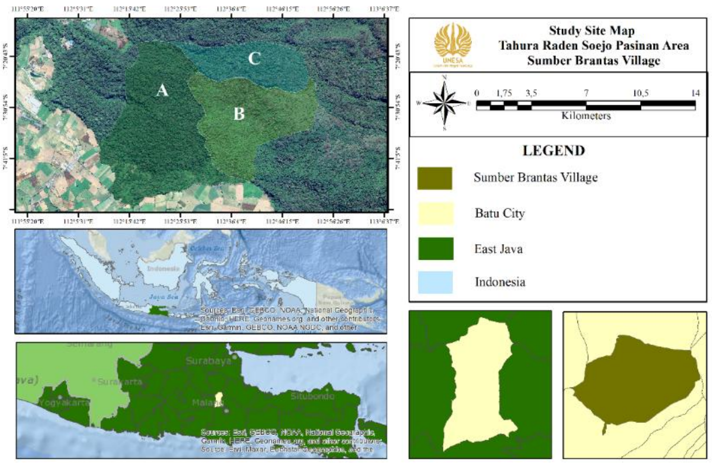

Fig. 1. Research location Tahura Raden Soerjo Pasinan Area, Sumber Brantas Village (A. closed forest; B. open forest; C. post-fire forest)

Sampling method. Sampling of *pteridophyte* in this research used the cruise method by making direct observations and making transect lines according to the standard, which is along 10-30% of the circumference of the research area. The number of plots in each transect was determined using a fixed interval of 25 meters between plots (Priambudi *et al*., 2022; Moran, 2004), so the number of plots obtained varied depending on the length of the transect in each vegetation. All individuals of *pteridophyte* found within the plots were recorded and counted to obtain comprehensive data on species composition and abundance. This approach ensured the representation of both terrestrial and epiphytic growth forms in varying microhabitats. The tools used in this research include Realme Narzo 50 smartphone with 50MP main camera, thermo-hygrometer model ST70TH, Soil meter 3 in 1 Soil Moisture Tester, Soil thermometer with temperature range specifications: 0 + 100°C Div: 1°C, and lux meter.

Species identification. *Pteridophyte* samples were identified based on leaf morphological characters, and sorus. Both vegetative and fertile (spore-producing) individuals were observed, especially to ensure diagnostic accuracy of reproductive traits such as indusium presence and sorus arrangement. Identification followed classical references including Holtum (1968) and van Steenis (2010), and was cross-verified using modern taxonomic resources such as the Checklist of Ferns and Lycophytes of the World and the Pteridophyte Phylogeny Group I classification (PPG I) (Schuettpelz et al., 2016). Alignment of identification results is done with Plant Of World Online (https://powo.science.kew.org/), Global Plants on JSTOR (https://plants.jstor.org/), Inaturalist (https://www.inaturalist.org/), Tropicos (https://www.tropicos.org/), Ferns and lycophytes of world (https://www.fernsoftheworld.org/).

To minimize identification errors, field identification was supported by photographic documentation and verification using multiple sources. Particular attention was given to epiphytic taxa and species with overlapping morphological characters. A checklist of recorded species and their diagnostic traits is provided in the appendix, which serves as a supplementary identification key.

Data analysis. Data collected in the form of an inventory of species, families, and the number of individuals of each forest vegetation were analyzed using an ecological index. Ecological index is one of the important parameters to measure and determine the condition of an ecosystem based on the composition and structure of the species community in it (Dewi *et al*., 2023). The parameters used in this research include the Shannon-Wiener diversity index (Odum, 1971), the evenness index using Pielow evenness indices (Ludwig & Reynolds, 1988), and the dominance index using Simpson's dominance index (Odum, 1971). This research used the Canonical Correspondence Analysis (CCA) method to evaluate the relationship between species composition and environmental factors. CCA makes it possible to visualize how each environmental parameter affects the distribution of species at different sites (Braak, 1987). The analysis was conducted using PAST 4.03 software. This research uses Pearson's correlation analysis to determine the correlation between environmental physics parameters (Nazar et al., 2024).

The diversity index was analyzed using the Shannon-Weiner diversity index with the formula:

$$H' = \sum Pi \ln Pi$$

Notes:
H' = Diversity index
S = Number of Species found
Pi = Number of individuals of the **i** species divided by the total number of individuals
Pi $= \frac{ni}{N}$
ni = Number of individuals of their species divided by the total number of individuals
N = total number of individuals

Shannon-Weiner defines the magnitude of species diversity as follows: A value of H' > 3 indicates that the diversity of species in a transect is high; A value of 1 ≤ H' ≤ 3 indicates that the species diversity of a transect is medium moderately abundant; and A value of H' < 1 indicates that the species diversity at a transect is low.

The evenness index was analyzed using Pielow evenness indices using the formula:

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

Notes:
E = Evenness index
H' = Diversity index
S = Number of species
ln = Natural logarithm

The evenness index ranges from 0-1 with the following categories: 0 < E ≤ 0.4 small evenness, stressed community; 0.4 < E ≤ 0.6 moderate evenness, unstable community; and 0.6 < E ≤ 1.0 high evenness, stable community.

The Dominance Index was calculated using Simpson's dominance index formula:

$$C = \sum (\mathrm{pi})^2$$

Notes:
C = Species dominance index
pi = Proportion of the number of individuals *pteridophyte* of the **I**-th species to the total number of individuals of all species.

The criteria for species dominance index values are: 0 < C ≤ 0.5 low dominance; 0.5 < C ≤ 0.75 medium dominance; and 0.75 < C ≤ 1 high dominance.

RESULTS AND DISCUSSION

***Pteridophyte* species inventory.** Based on field observations in the Pasinan area of Tahura Raden Soerjo, a total of 31 *pteridophyte* species were recorded and classified into 11 families. The most species-rich family was *Aspleniaceae* (8 species), followed by *Dryopteridaceae* (7 species), and one species from the lycophyte family *Selaginellaceae*. In terms of habitat type, 19 species were classified as terrestrial and 12 as epiphytic. Closed forest vegetation supported the highest species richness (19 species from 11 families), followed by open forest (17 species from 8 families) and post-fire forest (9 species from 6 families).

This research assessed the diversity of *pteridophytes* as bioindicators of forest ecosystem quality based on species dominance, frequency of occurrence, and correlation with abiotic environmental parameters. Closed forests exhibited the highest diversity (20 species), dominated by terrestrial and epiphytic taxa such as *Asplenium nidus*, *A. tenerum*, and *Dryopteris adnata*. These species are known to prefer moist, shaded microhabitats with low light intensity and stable temperatures. They exhibit a narrow ecological amplitude and strong dependence on undisturbed microclimatic conditions, making them effective indicators of intact forest ecosystems (Mehltreter *et al*., 2010; Karger *et al*., 2011).

Open forests harbored species with broader ecological amplitudes, such as *Dryopteris wallichiana* and *A. polyodon*, which tolerate moderate light and more open soil conditions. These species are morphologically adapted to transitional environments, possessing traits such as thicker fronds, creeping rhizomes, and linear sori. Their presence reflects moderate ecological disturbance and a shift from shade-loving to light-tolerant fern communities (Silva *et al*., 2018).

In post-fire vegetation, species richness declined markedly (9 species), with dominance by early successional pioneers such as *Selliguea enervis* and *A. macrophyllum*. These species are tolerant of high irradiance, low humidity, and fluctuating temperatures. Their reproductive traits, such as exposed or weakly protected sori, facilitate rapid spore dispersal in open and disturbed environments (Sharpe *et al*., 2010; Poppinga *et al*., 2015). Their presence reflects a forest ecosystem undergoing early-stage ecological succession following disturbance (Carvajal-Hernández *et al*., 2017; Nuryanti *et al*., 2023).

Additionally, *S. ornata* (Lycopodiophyta) was recorded across all vegetation types, including post-fire areas. As a generalist pioneer with rapid colonization ability, this species contributes to ground cover recovery and soil stabilization in degraded habitats. Although not a true fern, its consistent presence supports early successional dynamics and highlights its ecological importance in disturbed forest ecosystems (Kessler *et al*., 2014).

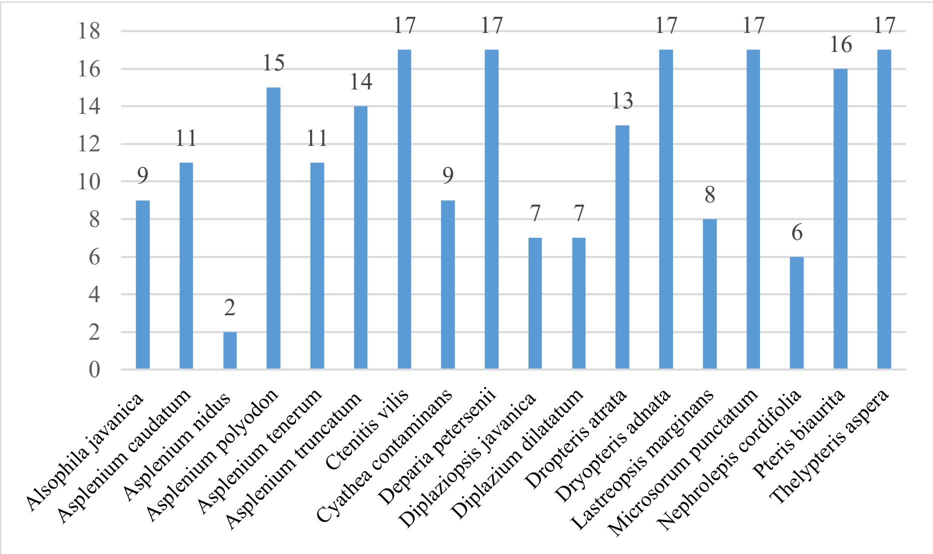

Fig. 2. Inventory results of *pteridophyte* in closed forest

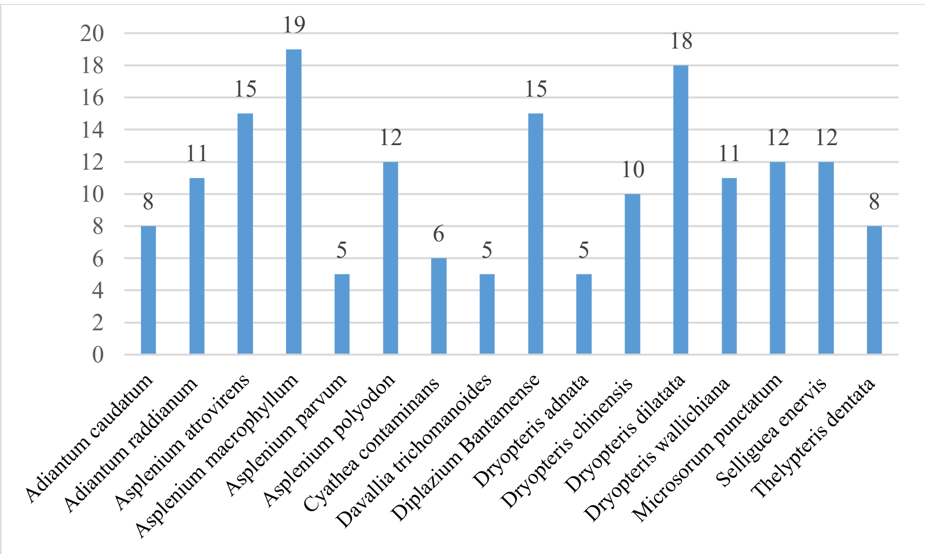

Fig. 3. Inventory results of *pteridophyte* in open forest

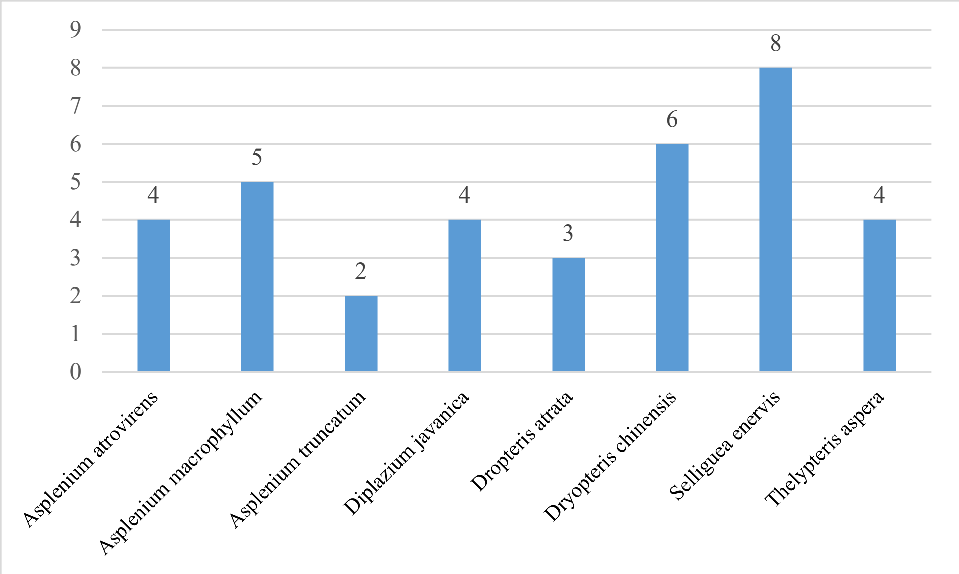

Fig. 3. Inventory results of *pteridophyte* in post-fire forest

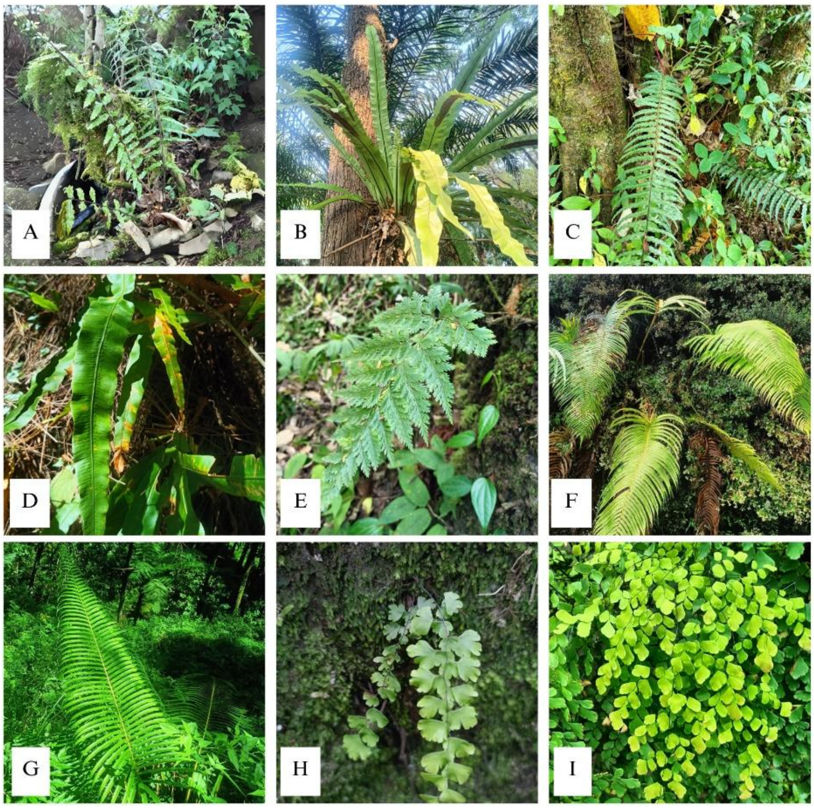

Fig 4. *Pteridophyte* diversity, A) *Asplenium parvum*; B) *Asplenium nidus*; C) *Asplenium tenerum*; D) *Microsorum punctatum*; E) *Davalia trichomanoides*; F) *Cyathea contaminans*; G) *Dryopteris dilatata*; H) *Adiantum caudatum*; I) *Adiantum raddianum*

Ecological index of each forest vegetation. The ecological index results describe the gradient of ecosystem quality across the three forest vegetation types. The results of the research can be seen in Table 2. From the results of the inventory of *pteridophyte* diversity, the values of diversity index, evenness and species dominance can be determined as follows. In closed forest vegetation, the diversity index value of 2.85 indicates a moderate and diverse community. An evenness value of 1.0 reflects an even distribution of species and a stable community. The dominance value of 0.1 indicates that there is no overly dominating species. Open forest vegetation had a diversity value of 2.76 also in the medium category, with an evenness of 1.0 and a dominance of 0.1, indicating similar community conditions to the closed forest. In contrast, post-fire vegetation had a very low diversity value of 0.23, low evenness of 0.1 and high dominance of 8. This indicates high environmental pressure so that only a few species are able to survive and dominate, while other species are not found.

Table 2. Index values of species diversity, evenness, dominance

Vegetation types	Spesies total	H'	E	C
Closed forest	19	2,85	1,0	0,1
Open forest	17	2,76	1,0	0,1
Post-fire forest	9	0,23	0,1	8

The Shannon-Wiener diversity index in closed forests (2.85) and open forests (2.76) shows a level of diversity that falls into the medium category of moderately abundant. Both habitats have relatively high diversity due to ecosystem conditions that still support the existence of various *pteridophyte* species. Closed forests are characterized by a stable environment with a constant level of humidity and temperature due to a dense canopy so that various *pteridophyte* species can develop optimally (Carvajal-Hernández *et al*., 2017). Although open forests have higher sunlight exposure than closed forests, they still provide a fairly favorable environment for *pteridophyte* species, especially species that are tolerant of high light intensity (Zhu *et al*., 2016). Community stability reflected by Pielou's evenness index of 1 for both habitats indicates an even distribution of species. This indicates the absence of dominance of certain species, as also supported by Simpson's dominance index which is very low (0.1), so that the communities in these two habitats can be said to be stable and ecologically healthy. The similarity of ecological index values in these two habitats can be explained by the capacity of closed and open forests to support diverse *pteridophyte* communities. Although environmental factors such as light and humidity are different, the *pteridophyte* species present are able to adapt well to these conditions, making these ecosystems have almost equal diversity and evenness. Differences in species abundance reflect differences in habitat preferences influenced by specific environmental conditions in each vegetation type (Abotsi *et al*., 2020). These results are in line with previous studies showing that tropical *pteridophyte* species have a fairly wide environmental tolerance, thus supporting high species diversity in both habitats (Watkins *et al*., 2007; Ramírez-Barahona *et al*., 2011).

Very different conditions were observed in the post-fire forest, with a very low Shannon-Wiener diversity index value (0.23). This value indicates that species diversity in this habitat is very low, and only dominated by a few select species that can survive or quickly colonize after the fire, such as *S. enervis* and other pioneer *pteridophyte* species. The very low Pielou's evenness index (0.1) indicates an uneven distribution of species, where one or two species dominate the habitat, while other species are few or even absent. This is also reinforced by Simpson's very high dominance index (8), indicating the specific dominance of some species. The low ecological index value in this habitat is closely related to the impact of fire on the ecosystem. Fire causes loss of fertile topsoil, changes in soil physical and chemical properties, and reduced soil moisture (Memoli *et al*., 2020; Solomun *et al*., 2021). These conditions created an extreme environment, where only pioneer *pteridophyte* species tolerant to environmental stress were able to survive. However, these conditions also reflect the beginning of the ecological succession process, where pioneer species play an important role in improving environmental conditions for subsequent species (Nuryanti *et al*., 2023).

Correlation of environmental parameters to species distribution. The distribution of *pteridophyte* species in each vegetation type in Tahura Raden Soerjo is influenced by variations in physical environmental parameters including light intensity, temperature, humidity, and soil pH. To determine the relationship between species distribution and these environmental factors, CCA was conducted. This analysis aims to interpret the distribution patterns of *pteridophyte* species against environmental changes in closed, open and post-fire forest vegetation.

Based on the analysis of environmental physics parameters and species distribution across forest vegetation types, CCA revealed clear correlations between species presence and environmental conditions, as visualized in the biplots (Figure 3). The biplots show that species like *Dryopteris adnata* (Da) and *Pteris biaurita* (Pb) are associated with closed forest habitats characterized by high humidity and low light intensity. In contrast, species such as *Selliguea enervis* (Se) and *Asplenium macrophyllum* (Am) are linked to high light and temperature conditions, indicating their adaptability to disturbed environments like post-fire forests. Meanwhile, in open forest areas that retain some canopy cover, species like *Dryopteris wallichiana* (Dw) and *Asplenium polyodon* (Apol) demonstrate moderate tolerance and more even distribution under intermediate conditions.

Correlation analysis between environmental physical parameters using Pearson's correlation analysis was conducted to examine the linear relationship between environmental variables in three vegetation types. The results of the analysis in Table 3 show that light intensity has a very strong positive correlation with soil temperature, with a correlation coefficient of r = 0.998 and significance p = 0.042. Soil temperature also shows a very strong positive correlation with air temperature, with a correlation coefficient of r = 0.998 and significance p = 0.036, indicating that changes in temperature in the soil layer are in line with changes in temperature in the surrounding air.

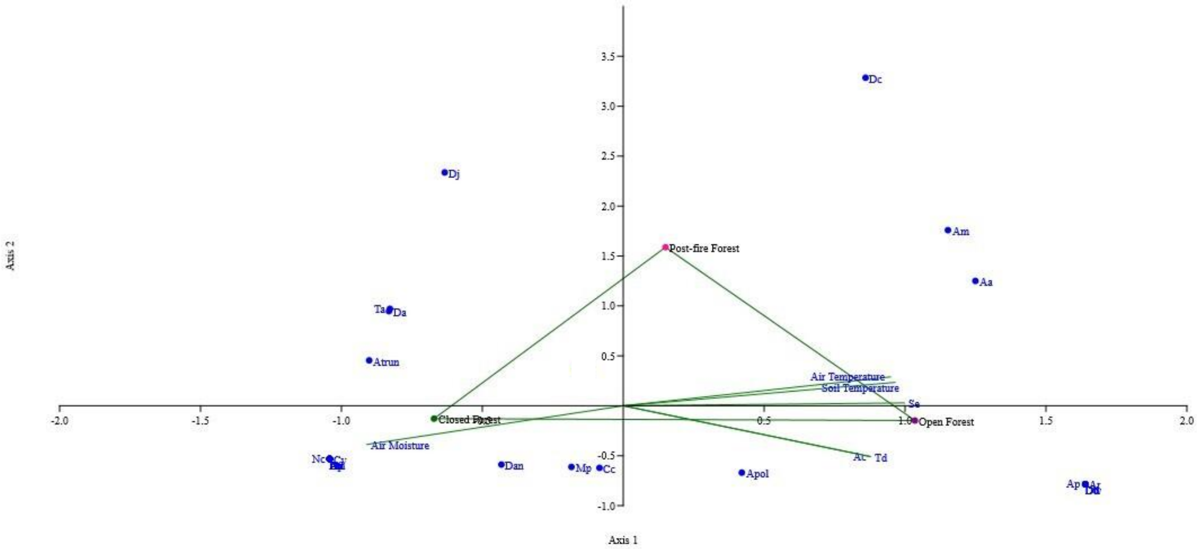

Fig 5. Biplot CCA correlation of environmental parameters with species distribution

Table 3. Significant correlation between physical parameters

		Light intensity	Soil temperature	Air temperature
Light intensity	Correlation	1	0,998*	0,092
	Sig.	-	0,042	0,078
Soil temperature	Correlation	0,998*	1	0,998*
	Sig.	0,042	-	0,036
Air temperature	Correlation	0,992	0,998	1
	Sig	0,078	0,036	-

The biplots and scores from this CCA analysis help to clarify the distribution patterns of species under different environmental conditions. The biplots show clear correlation relationships between species and environmental factors, making it easier to understand the ecological patterns of each species in correlation to different forest conditions. The data obtained showed that environmental factors such as light intensity, soil temperature, soil moisture, and vegetation type (closed forest, open forest, and post-fire forest) had a significant influence on the presence and abundance of *pteridophyte* species in the research site (Costa *et al*., 2018).

The light intensity, soil temperature, soil pH, air temperature, vector points to the upper right, indicating that habitats with higher light intensity tend to favor species adapted to these conditions.

These conditions are favorable to pioneer species that tend to thrive in open forest and post-fire forest, where sunlight can reach the ground more intensely. Species such as *S. enervis* that are found in greater abundance in post-fire areas show adaptation to environments with high light intensity and may have the ability to regenerate quickly under such conditions, supporting the theory that certain *pteridophyte* species serve as pioneers in ecosystems disturbed by fire (Akomolafe *et al*., 2023).

Physical parameters such as soil temperature and soil moisture also appear to influence species distribution patterns. Species located in the direction of the soil moisture vector show adaptation to more humid environments, such as under closed forest canopies. These conditions favor the presence of *pteridophyte* species that require high humidity for their life cycle, such as *D. adnata* which is known to grow well in areas of high moisture (Oseguera-Olalde *et al*., 2022). Long soil temperature vectors have also shown that certain species tend to be more resistant to more extreme soil temperature conditions (Ridhwan *et al*., 2022).

CCA analysis also showed that vegetation type had a significant influence on the distribution of *pteridophyte* species. In post-fire forest areas, several pioneer species are dominant, such as *S. enervis* and other species that can grow in disturbed environmental conditions (Nuryanti *et al*., 2023). Their presence suggests that post-fire forests tend to favor species with high tolerance to light and temperature fluctuations, as well as rapid regeneration ability, which supports the hypothesis that post-fire forests provide an ecological niche for pioneer species (Pang *et al*., 2018). Closed forests are characterized by a more stable and humid environment, which favors the presence of *pteridophyte* species that are intolerant of direct light. In this research, species such as *D. adnata* were more abundant in these areas, which corresponds to their ecological preference for more shady and moist habitats. Dense or closed vegetation types can create a microclimate conducive to *pteridophyte* species that require high humidity for growth and reproduction (Ridhwan *et al*., 2022).

The results of this research have important implications in the context of environmental conservation and management. The variable distribution of *pteridophyte* species based on vegetation type and environmental factors suggests that *pteridophyte* can serve as bioindicators of environmental quality (Walker & Sharpe, 2010), especially in identifying areas of habitat degradation or change (Nuryanti *et al*., 2023). The presence of pioneer species in post-fire forests, for example, maybe an early indication of ecosystem recovery after disturbance, while species sensitive to changes in light and moisture may indicate the stability of closed forest ecosystems.

To deepen understanding, Pearson correlation analysis between environmental physical parameters was conducted and showed significant relationships. In closed forests, light intensity was strongly negatively correlated with air and soil humidity, indicating that the dense canopy was able to maintain microhabitat humidity (Ocholla *et al*., 2022). In open forests, light intensity is positively correlated with soil and air temperature, while temperature is negatively correlated with humidity, indicating microclimate fluctuations due to the open canopy, while temperature and humidity show a sharp negative correlation, indicating extreme conditions after disturbance (Grill *et al*., 2023). The connection between these environmental factors and species distribution is important to understand in designing rehabilitation strategies for habitats affected by wildfire. This approach enables the selection of appropriate species for revegetation based on ecological preferences, thereby supporting more effective ecosystem recovery.

Characteristics of dominant species in each forest vegetation type. This research identified indicator species for each vegetation type based on species dominance, frequency of occurrence, and their relative position to environmental parameters derived from CCA. The morphological characters analyzed included growth form, rhizome type, leaf morphology, and the type and position of sori. In closed forest vegetation, *Dryopteris adnata* and *Pteris biaurita* exhibited adaptations to low light and high humidity, characterized by creeping or erect rhizomes and sori protected by indusia, supporting reproductive efficiency in shaded, moist environments. In open forest vegetation, *A. polyodon* and *D. wallichiana* showed a more open growth habit, bipinnate fronds, and sori distributed along the veins, indicating adaptation to higher light exposure. In post-fire vegetation, *S. enervis* and *A. macrophyllum* displayed morphological traits such as thick fronds, creeping rhizomes, and simple sori as adaptations to harsh, disturbed environments. Although not a true *pteridophyte*, *S. ornata* was also present as a pioneer species, characterized by microphyllous leaves and terminal strobili, reflecting its role in early colonization of disturbed areas.

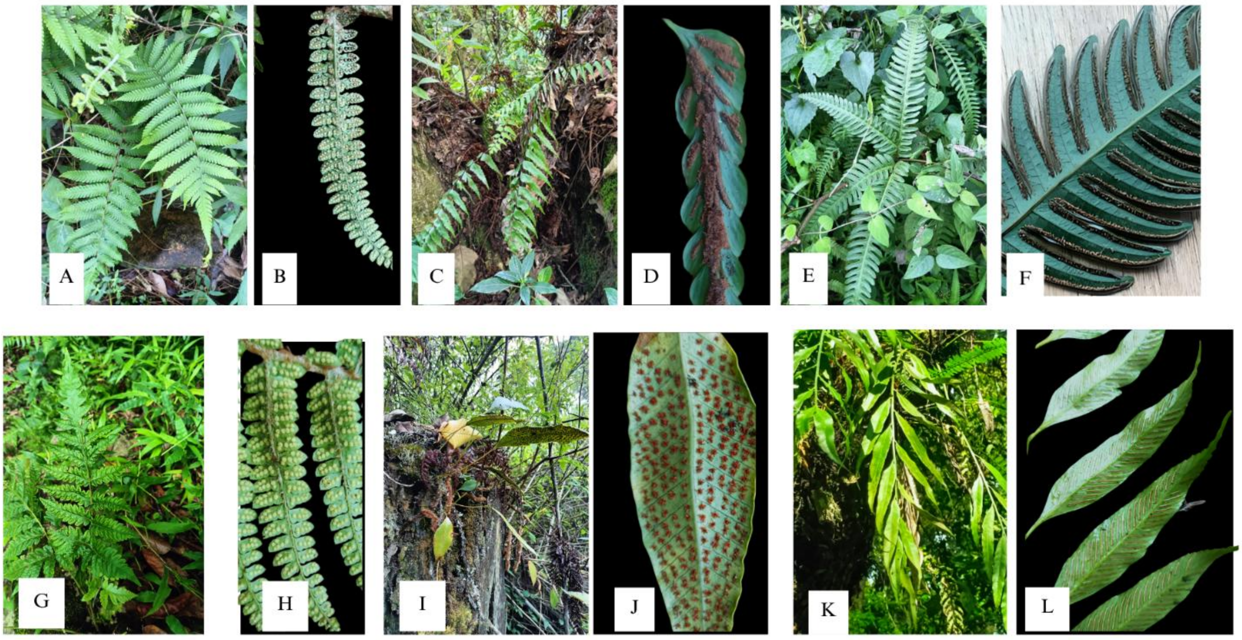

Fig 6. Dominant species in each vegetation, A) *Dryopteris adnata*; B) Sorus *Dryopteris adnata*; C) *Asplenium polyodon*; D) Sorus *Asplenium polyodon*; E) *Pteris biaurita*; F) Sorus *Pteris biaurita*; G); *Dryopteris wallichiana*; H) Sorus *Dryopteris wallichiana*; I) *Selliguea enervis*; J) Sorus *Selliguea enervis*; K) *Asplenium macrophyllum*; L) Sorus *Asplenium macrophyllum*

Each forest vegetation type in Tahura Raden Soerjo exhibited dominant *pteridophyte* species with distinctive morphological traits that reflect their ecological adaptability and potential as bioindicators. In closed forests, *D. adnata* and *P. biaurita* dominated under humid and shaded conditions. *D. adnata* shows erect rhizomes, bipinnate fronds with coarse surfaces, and reniform indusiate sori, adapted for moisture retention and microhabitat support (Punetha *et al*., 2018). *P. biaurita* possesses creeping rhizomes, smooth fronds, and marginal sori protected by a false indusium, supporting rapid colonization in moist environments (Rai & Srivastava, 2024; Praveen & Pandey, 2020).

In open forest, *D. wallichiana* and *A. polyodon* prevailed. *D. wallichiana* has coarse-textured pinnate fronds and indusiate sori, tolerating moderate to high light (Díez & Pacheco, 2005), while *A. polyodon* combines terrestrial and epiphytic growth, linear sori, and dark-scaled rhizomes, indicating tolerance to fluctuating humidity (Mehltreter, 2010). Their morphological features reflect adaptation to open canopy and microclimatic variation. Post-fire vegetation was dominated by *S. enervis* and *A. macrophyllum*, species with exposed or false-indusiate sori, which facilitate faster spore dispersal without dependence on microclimate conditions (Poppinga *et al*., 2015). *S. enervis*, an epiphyte with thick, waxy leaves and creeping rhizomes, thrives on nutrient-poor substrates (Watkins *et al*., 2007), while *A. macrophyllum* exhibits rapid vegetative regeneration and high light tolerance (Sharpe *et al*., 2010). These traits make them effective pioneers in disturbed environments. Additionally, *S. ornata*, a lycophyte with rapid colonization traits, also dominated, indicating its role in early ecological recovery (Kessler *et al*., 2014).

CONCLUSION

This research revealed that *pteridophyte* species diversity in the Tahura Raden Soerjo, Batu, East Java, has great potential as a bioindicator of ecosystem quality. Based on ecological index analysis, closed and open forest vegetation types showed high diversity and good community stability, while post-fire forest showed low diversity with the dominance of certain species. CCA revealed significant relationships between the distribution of *pteridophyte* species and environmental factors such as light intensity, soil pH, and moisture, confirming species specific adaptations to habitat conditions. These results suggest that *pteridophyte* communities can provide a comprehensive picture of forest ecosystem health and the impact of environmental disturbances. Further research is recommended to explore the temporal dynamics of *pteridophyte* communities in response to long-term environmental changes, including climate change, to support more sustainable forest conservation management. However, limitations due to this research's reliance on solely morphological identification remain for grouped taxa which urges the need for future integrative approaches implementing molecular methods such as DNA barcoding.

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