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RESEARCH ARTICLE

Potential of morphology-based Pterydophyta diversity in supporting field-based practicum of low plant botany learning

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Abstract: Field-Based Practicum (FBP) about Pterydophyta diversity material in Low plant botany learning is very important, even though the facts in the field show that FBP is still minimally carried out. This research aims to utilize the potential diversity of Pterydophyta in the Tuban-Lamongan Pantura area as a support for FBP about low plant botany learning. The type of research is descriptive exploratory with a transect method, which divides the research area into five plots. Data collection techniques involve observing abiotic parameters and fern morphology in each plot and counting the number of individuals of each species. Data analysis used the Shannon & Wiener index for diversity and qualitative descriptive analysis for morphology. The research results showed 19 species of ferns with 210 individuals divided into two classes, namely Polypodiopsida and Psyotopsida. The fern diversity index is in the medium category (H´=2.10). The diversity of ferns obtained shows that the Tuban-Lamongan Pantura area has a high potential to support FBP about low plant botany learning to provide insight and direct experience to students about the diversity of ferns in the surrounding environment.

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Introduction

Forest vegetation ecosystems in Indonesia have abundant flora diversity, one of which is the diversity of Pterydophyta (Azrai et al., 2024; Deng et al., 2024; Juliasih & Adnyana, 2023b; Qian et al., 2023). Pterydophyta is highly diverse in Indonesia and is widely studied in terms of morphology (Azrai et al., 2024; Pramudita et al., 2023). Pterydophyta (ferns) is the oldest dominant vascular plant group without seeds and flowers that have free spores with a diversity of more than 13.500 species worldwide (De-Villa & Lagat, 2023; Di-Michele et al., 2024; Guillen-Otero et al., 2024; Ibiye et al., 2023; Katayama et al., 2024; Marasinghe & Daulagala, 2024; Michalak et al., 2024; Randrianarimanana et al., 2024; Xie et al., 2023). Ferns are classified in Equisetales, Psilotopsida, Marattiopsida, and Polypodiopsida (Kumar et al., 2022). The diversity of ferns in the form of morphology, global distribution, and phylogenic distribution is mainly found on the top of tropical mountains with humidity and temperature ranging from 21-27°C (Fujiwara et al., 2023; Juliasih & Adnyana, 2023a; Khan et al., 2024; Michel et al., 2023; Moulatlet et al., 2024; Qian et al., 2024). Ferns are known as cosmopolitan plants that can proliferate horizontally and vertically in water (hydrophytes), attach to other plants (epiphytes), and grow on the rest of dead plants (saprophytes) (Afifah et al., 2023; Rahmawati & Santhyami, 2023; Wheeler et al., 2024). The body parts of ferns are divided into roots, stems, and leaves (Khotimah et al., 2023). Ferns are an essential component of the ecosystem due to their rapid photosynthetic ability and their ability to increase microbial diversity in the soil (Lu et al., 2023; Riyanto et al., 2024; Yi et al., 2023; Zeng et al., 2024). In its development, the diversity of Pterydophyta can be utilized to support 21st-century learning models, one of which is to support Field-Based Practicum (FBP) learning of Low plant botany. This is in alignment with the research findings of Boileau and O'Donoghue (2024) who emphasized the importance of providing students with outdoor learning experiences.

Practicum is one of the learning methods that can improve student understanding (Yuhanafia et al., 2024). Practicum is considered the best innovation for educators to apply theory into practice and is essential in improving the quality of learning outcomes and processes (Li et al., 2023; Lolowang et al., 2023). In its implementation, practicum requires cognitive, interpersonal, creativity, collaboration, and critical thinking skills (Mubai et al., 2023). However, several factors cause practicum to be rarely implemented, such as the relatively long preparation time for practicum, the lack of availability of practicum equipment, and the high level of risk of practicum in the laboratory (Juniar et al., 2024). This is because the quality of practicum learning in Indonesia still needs to catch up to the development of existing industries (Suputra & Susanto, 2023). Therefore, FBP is one of the innovative learning methods that can be given to students to improve learning outcomes; this is because students understand the material directly and more meaningfully (Das et al., 2024; Sejati et al., 2023; Tariq et al., 2023). Through observation, FBP is conducted outside the laboratory, which benefits students by providing learning flexibility (Kandriasari et al., 2023; Nguyen & Nguyen, 2024). In addition, FBP can help students apply theoretical knowledge in the classroom in actual practice through skill development (Hande & Sharma, 2021; Joseph & Jamal, 2023; Lee & Davis, 2023).

So far, the FBP of Low plant botany learning material on Pterydophyta diversity is minimal. This is evidenced by several studies in various countries that only identify the diversity of Pterydophyta without integrating it into 21st-century learning, such as Ibrahim et al. (2024) in the Gunung Masigit Hunting Park area of Bandung; Dubuisson et al., (2024) in Africa; Fischer and Lobin (2024) in Rwanda; Michel et al. (2023) in the lowland tropical rainforest of Ecuador; Yoneoka et al. (2023) in regional Japan and Zhang et al. (2023) in Zhejiang Province. As a result, learning resources to support the FBP of learning Low plant botany are rarely found, so students also need help finding contextual learning resources that present the diversity of Pterydophyta. This directly impacts students' low understanding of Pterydophyta diversity and their inability to solve contextual problems critically. Therefore, the novelty of this research is to explore the potential diversity of Pterydophyta in the Tuban-Lamongan Pantura area based on morphology. This is because, so far, research has yet to be conducted to study the diversity of ferns in the Tuban-Lamongan coastal area with a morphological approach. In comparison, the study of morphology-based pteridophyta diversity is beneficial to support FBP in learning low-level plant botany. Our next novelty also utilizes the potential diversity of Pterydophyta to support the FBP of low-level plant botany learning as well as a form of integration in 21st-century learning. This FBP is expected to give students an in-depth understanding of Pterydophyta diversity and improve their critical contextual problem-solving skills.

Based on the description related to the diversity of Pterydophyta and the need for field-based practicum to support 21st-century learning models, the formulation of the problem in this study is how to utilize the potential diversity of Pterydophyta in the Tuban-Lamongan Pantura area based on morphology in supporting field-based practicum learning of low plant botany? The research objectives are to utilize the potential diversity of Pterydophyta in the Pantura Tuban-Lamongan area based on morphology in supporting field-based practicum learning of low plant botany.

Method

This is an explorative and descriptive research that describes the level of Pterydophyta diversity in terms of morphological characteristics directly in the Tuban-Lamongan Pantura area, as shown in Figure 1.

Figure 1. Location of the research plots in the Tuban-Lamongan Pantura area

The research was conducted on March 8, 2024. The research method used was the transect method, which divided the area into five plots. The transect method has the advantage of covering a large area quickly (Mwampeta et al., 2024). Instruments used include wooden stakes measuring 1 meter (4 pieces), raffia, stationery, a camera, a meter, a soil meter, a hygrometer, and a lux meter. The material used is the diversity of fern species found in the plot. Data collection techniques were carried out using exploratory techniques by directly observing the abiotic parameters of each plot, observing ferns in the plot based on their morphological characteristics, and counting the number of individuals of each species found in the plot. Data in this study are divided into two types: (1) quantitative in the form of the number of individuals of each species; (2) qualitative in the form of morphological characteristics of each species. The data analysis technique for the number of individuals of each species was carried out descriptively quantitatively using the Shannon & Wienner (1963) Index equation, which refers to Khalmuratova et al. (2021) in Equation 1, which is then interpreted into Table 1, which refers to Baderan et al. (2021). Meanwhile, data from morphological observations were analyzed descriptively and qualitatively to describe the morphological characteristics of each species.

$$H' = -\sum_{i=1}^{s} \text{pi}.\, ln\, \text{pi} \tag{1}$$

Description: H´ = Shannon-Wienner diversity index
pi = number of individuals found in *i* genus in a population
pi = $\frac{ni}{N}$ with; ni = number of individuals in one species;
N = total number of individuals of the species found
ln = Natural logarithm

Table 1. Diversity index value criteria

H´ Value	Diversity Criteria
H´ <1	Low level
1≤ H´ ≤3	Medium level
H´ >3	High level

Results and Discussion

Identifying Morphology of Pterydophyta

Abiotic factors strongly influence the growth of fern diversity. Therefore, abiotic parameters were observed in each research plot in the Tuban-Lamongan Pantura area, as shown in Table 2. Abiotic factors include soil pH, soil moisture, air temperature, light intensity, and air humidity. According to Umair et al. (2023), air temperature and rainfall are significant factors affecting fern diversity growth.

Table 2. Abiotic parameters for each plot

Plot Numbers	Abiotic Parameters				
	Soil pH	Soil Moisture	Air Temperature (°C)	Light Intensity (lux)	Air Humadity (%)
1	6,8	8	27	3072	96.1
2	6,2	4	26	2464	85.3
3	6,1	6	24	4966	81.6
4	6,2	2.5	30	1701	76.0
5	6,8	1	28	2163	74.1

The results of measuring abiotic parameters in various plots show that the highest soil pH value is in plots 1 and 5. which is 6.8. In contrast, The lowest pH value is in Plot 3. 6.1. However, the soil pH is considered ideal for fern growth. This is by Khairunisa & Wisanti (2023), who state that ferns thrive with soil pH between 5.5-6.5. Measurement of soil and air moisture parameters showed that plot 1 had the highest soil and air moisture compared to other plots, while plot 5 had the lowest soil and air moisture. Pramaisela et al. (2024) explained that ferns can grow and develop well with 60-90% humidity. Soil properties, including pH and soil moisture, play an essential role in the abundance and diversity of ferns (Cicuzza & Mammides, 2022). In addition, ferns tend to be in shady places, have shade, are relaxed, and have high levels of air humidity (Ibrahim et al., 2024; Singh & Chauhan, 2024). Air temperature measurements also show that Plot 4 has the highest air temperature, while Plot 3 has the lowest. Ferns thrive in tropical areas with a temperature range of 21-27°C due to these ideal temperature conditions (Rahmawati & Santhyami, 2023). Light intensity measurements showed that plot 1 had the lowest light intensity compared to the other plots, while plot 3 had the highest light intensity. Sianturi et al. (2021) explained that low light intensity is influenced by the absence of canopy and cloud cover; this condition is very suitable for fern growth habitat.

The results of research related to the diversity of ferns found in the Tuban-Lamongan Pantura area in the five plots showed that 19 species of ferns were classified into two classes, Polypodiopsida and Psyotopsida, with 210 individuals in total, as shown in Table 3.

Table 3. Diversity of ferns on each plot

Plot Numbers	Class	Species Name	Number of Individuals (ni)
1	Polypodiopsida	*Adiantum capillus-veneris*	26
		Pteris vittata	3
		Pellaea viridis	1
	Psylotopsida	*Helminthostachys zeylanica*	1
2	Polypodiopsida	*Pteris vittata*	12
		Pellaea atropurpurea	2
		Cheilanthes micropetris	5
		Adiantum latifolium	1
		Asplenium pinnatifidum	6
		Drynaria quercifolia	4
		Botrychium jenmanii	1
		Elaphoglossum stenoglossum	1
		Christella dentata	1
		Drynaria fortunei	3
3	Polypodiopsida	*Drynaria sparsisora*	4
		Platycerium bifurcatum	9
		Pteris vittata	1
		Asplenium pinnatifidum	1
		Drynaria quercifolia	1
4	Psylotopsida	*Asplenium trichomanes*	3
		Botrychium jenmanii	5
	Polypodiopsida	*Adiantum capillus-veneris*	18
		Pteris vittata	4
		Helminthostachys zeylanica	3
5	Polypodiopsida	*Amblovenatum terminans*	6
		Pteris vittata	58
		Elaphoglossum stenoglossum	1
		Drynaria sparsisora	13
		Oleandra distenta	4
		Asplenium pinnatifidum	9
		Microsorum pustulatum	3

Table 3 shows many ferns found in the plot 2 areas with ten species, with the most found being the *Pteris vittata* species. *Pteris vittata* species are found because of their ability to adapt to various types of soil and live in extreme environments. Besides that, *Pteris vittata* can also extract heavy metals in the soil, commonly known as phytoremediation (Widyastuti & Surya, 2023). Plot 1 is the tiniest plot where ferns are found, namely, only four types of species. However, in plot one, many species of *Adiantum capillus-veneris* were found, with a total of 26 individuals. *Adiantum capillus-veneris* species is a cosmopolitan fern species that lives in various niches (Rachmalia et al., 2023). In plots 3 and 4. fern species were found with the same number of species, namely five species with different types. In plot 3. the most species found were *Platycerium bifurcatum*, while in plot 4. the most species found were *Adiantum capillus-veneris*. *Platycerium bifurcatum* species are found attached to trees as their host. This is by Wu & Brock (2023), who state that *Platycerium bifurcatum* is an epiphytic plant.

In plot 5. 7 types of fern species were found. The most common fern species found was *Pteris vittata* in the plot 5 area with 58 individuals. In addition, *Pteris vittata* species were also found in all plots. This is per the opinion of Sukmawati et al. (2024) that *Pteris vittata* is known for its ability to live in various types of substrates and ecosystems so that it is widely distributed. *Pteris vittata* is also known for its ability to hyperaccumulate arsenic (Kohda et al., 2024). In addition, many fern species are only found in one individual in several plots, such as *Pellaea viridis, Helminthostachys zeylanica, Adiantum latifolium, Botrychium jenmanii, Elaphoglossum stenoglossum, Christella dentata, Asplenium pinnatifidum, Drynaria quercifolia* and *Elaphoglossum stenoglossum*. The ferns found were the Polypodiopsida class found in all plots with a small number of species, while the Psilotopsida class was only found in plot 1 and plot 4 with a small number of species. This is under Azzahro (2022), who states that Polypodiopsida is a class of ferns with the most members. In addition, almost all species of the Polypodiopsida class have been identified. They are widely distributed in the tropics and subtropics, with the majority of species living epiphytically and in modern fern groups, so this type is included in a group that has high adaptation, which causes the distribution of this group to expand (Inelia et al., 2023; Isa et al., 2023). Hidayah, (2019) explains that the Psilotopsida class is an ancient fern; many of these ferns have become fossils, while Polypodiopsida ferns are accurate or actual ferns.

Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6 present images of the morphological characteristics of ferns found in the Tuban-Lamongan Pantura area according to each plot. The results of observations of the morphological characteristics of the ferns found are presented in Table 4.

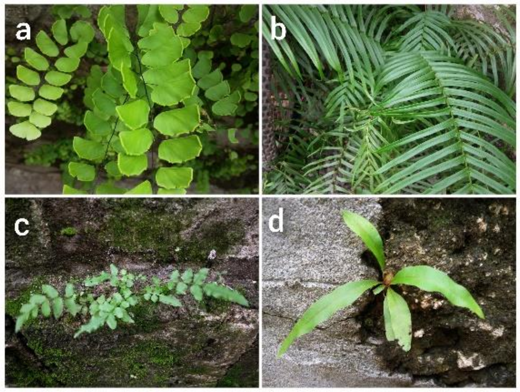

Figure 2. Fern species in plot 1: a) *Adiantum capillus-veneris*; b) *Pteris vittata*; c) *Pellaea viridis*; d) *Helminthostachys zeylanica*

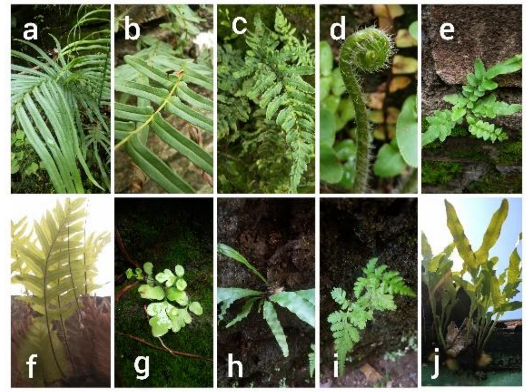

Figure 3. Fern species in plot 2; a) *Pteris vittata*; b) *Pellaea atropurpurea*; c) *Cheilanthes micropetris*; d) *Adiantum latifolium*; e) *Asplenium pinnatifidum*; f) *Drynaria quercifolia*; g) *Botrychium jenmanii*; h) *Elaphoglossum stenoglossum*; i) *Christella dentata*; j) *Drynaria fortune*

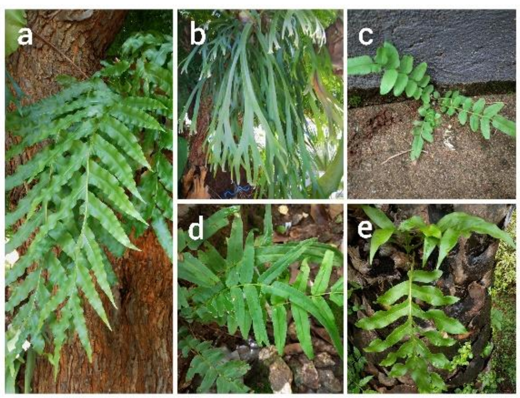

Figure 4. Fern species in plot 3: a) *Drynaria sparsisora*; b) *Platycerium bifurcatum*; c) *Pteris vittata*; d) *Asplenium pinnatifidum*; e) *Drynaria quercifolia*

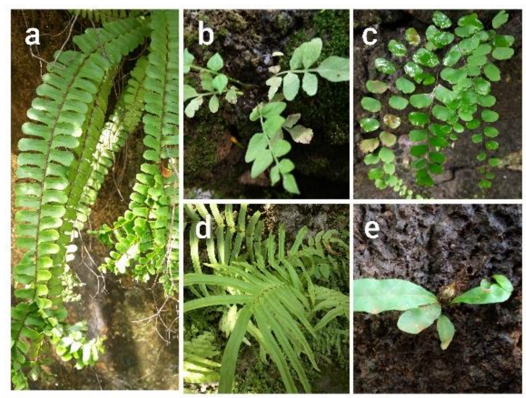

Figure 5. Fern species in plot 4; a) *Asplenium trichomanes*; b) *Botrychium jenmanii*; c) *Adiantum capillus-veneris*; d) *Pteris vittata*; e) *Helminthostachys zeylanica*

Figure 6. Fern species in plot 5; a) *Amblovenatum terminans*; b) *Pteris vittata*; c) *Elaphoglossum stenoglossum*; d) *Drynaria sparsisora*; e) *Oleandra distenta*; f) *Asplenium pinnatifidum*; g) *Microsorum pustulatum*

Table 4. Observation of morphological characteristics of each species

Species Name	Morphological Characteristics				
	Root	Stem	Leaf	Sorus	Rhizoma
Adiantum capillus-veneris	Rhizoid	Black, Spreading, smooth, shiny	Sterile leaves, macrophyllous, shiny light green, curved round, serrated edge	On the edge of the fertile leaf, brownish yellow, small round, brown	Branched, small short, scaly
Pteris vittata	Fibrous, calyptra	Brown, spreading, hard	Sterile leaves, macrophyllous, long-pinnate compound, dark green, sharp tip and longer	Elongated at the edge of fertile leaves, small round, brown	Short, stiff, spreading, green when young and light brown when old
Pellaea viridis	Rhizoid	Light green, spreading	Sterile leaves, macrophyllous, round, serrated edges, dark green above and light green below	Below along the edge of fertile leaves, small round, brown	Small, short, spreading, scaly
Elaphoglossum stenoglossum	Rhizoid	Black, smooth	Sterile leaves, macrophyllous, dark green, shiny, wavy, elongated	Below along the edge of fertile leaves, small round, brown	Small, short, scaly
Helminthostachys zeylanica	Rhizoid	Brown, black, hard	Sterile leaves, macrophyll, pinnate, pointed tip, dark green	On stem at base of midrib sterile, small round, brown	Short, stiff, spreading
Drynaria sparsisora	Fibers (sporophytes), calyptra	Hard, brown	Sterile leaves, macrophyll, dark green, fingered, wavy, smooth	Located on the underside of fertile leaves, small round, brown	Long, tight, attached to the host, branched, scaly
Platycerium bifurcatum	Fibers (sporophytes), calyptra	Light brown, round	Fertile leaves, macrophyll, green, branched like deer antlers, curled tips	Located on the underside of fertile leaves, small round, brown	Spreading, flat, attached to the host
Pellaea atropurpurea	Rhizoid	Hard, light green	Sterile leaves, macrophyll, light green, oval, serrated edges	Located on the underside of fertile leaves, small round, brown	Short, spreading, scaly, curly, reddish brown
Cheilanthes micropetris	Rhizoid	Hard, spreading, smooth-haired	Sterile leaves, macrophyllous, pinnately oval, wavy, light green, smooth-haired	Located on the underside of fertile leaves, round and oval	Spreading, hard, upright, scaly, short, tight
Adiantum latifolium	Rhizoid	Light green, soft, long, slender, smooth-haired	Sterile leaves, microphyllous, round, curled, hairy, curved, thin	Located on the underside of fertile leaves, brownish black	Short, spreading, small-branched, brown
Amblovenatum terminans	Fibers (sporophytes)	Dark green, hard	Sterile leaves, macrophyll, parallel, long, dark green, smooth	Located on the lower edge of fertile leaves, small round, brown	Long, tight
Asplenium pinnatifidum	Rhizoid	Green, soft, shiny	Sterile leaves, macrophyll, round, serrated edge, pointed tip, oval	Located on the underside of the fertile leaf edge, small round, brown	Short, spreading, tight
Drynaria quercifolia	Fibrous (sporophyte), calyptra	Brown, hard, long	Sterile leaves, macrophyll, light green, fingered, pinnate, blunt tip	Located on the lower edge of the fertile leaves, arranged in rows, small round, brown	Tight, long, creeping, scaly
Christella dentata	Rhizoid	Light green, long, slender, smooth-haired	Sterile leaves, macrophyllous, compound, fingered, sharp tip, rounded edge	Below along the edge of the fertile leaf, small round, brown	Short, small, scaly
Drynaria fortunei	Rhizoid	Light green, long, round	Sterile leaves, microphyllous, parallel, compound, wavy, tip rounded	Below along edge of fertile leaf, small round, brown	Round, hairy, scaly, brown
Botrychium jenmanii	Rhizoid	Soft, light green	Sterile leaves, macrophyllous, compound, rounded, wide rounded tips	Below surface fertile leaves, small round, brown	Short, small

Species Name	Morphological Characteristics				
	Root	Stem	Leaf	Sorus	Rhizoma
Asplenium trichomanes	Fibrous (sporophyte), smooth	Keras, coklat	ard, brown Leaves sterile, macrophyllous, compound, small round, serrated edge, rounded leaf tip	Below surface edge of fertile leaf, small round, brown	Long, creeping, hairy
Microsorum pustulatum	Fibers (sporophytes), smooth	Hard, light green	Sterile leaves, macrophyll, light green, fingered, wide	Below surface edge of fertile leaves, small round, brown	Short, round hairy
Oleandra distenta	Fibers (sporophytes), smooth	Hard, dark green, smooth	Leaves sterile, macrophyllous, dark green, wide smooth, parallel	Crosswise below surface of fertile leaves, small round, brown	Creeping, round, hairy

Almost all of the 19 fern species found have root morphology in the form of saprophytes and rhizoids. Ferns have rhizoid roots in the gametophyte generation, while ferns will show the characteristics of fibrous roots in the sporotive generation (Kurnia, 2023). Observations also show that the stems of ferns have a rigid structure that is green when the plant is young and turns brown when the plant is old, such as in the species *Pteris vittata. Pteris vittata* has a dark brown rhizome base that spreads (Ramndana et al., 2023). Observations of fern stem morphology also show the presence of fine hairs covering part of the stem surface, such as in the species *Cheilanthes micropetris, Adiantum latifolium*, and *Christella dentata*. This is per Ulfa et al. (2023a), which states that the stems of ferns are covered mainly by several light brown fine hairs that are sparsely distributed along the stem, but more and more fine hairs are found near the roots. In addition, the species *Christella dentata* has brown scales on its rhizome (Majid et al., 2022). The species *Adiantum capillus-veneris* has a shiny black stem and looks slippery; this is what distinguishes it from the other fern species found, in accordance with the opinion of Nurcahyani (2021), which states that *Adiantum capillus-veneris*, commonly known as suplir, has leaf stalks and curved stems that are shiny, black and smooth. In Unayah & Widodo (2023), it is explained that the morphological characteristics of ferns are influenced by the genetic characteristics of these plants and environmental factors, such as climate change, temperature, soil type, soil conditions, altitude, and humidity.

The leaf morphology of ferns found has a variety of diversity; there are leaves that have curved, pinnate, fingered, and parallel leaf bones. Most fern leaves grow in compounds and include macrophilous leaves. The findings Sofiyanti et al. (2020) show that most ferns have linear and alternate compound leaves. In addition, compound leaves are a common form of fern leaf morphology (Ulfa et al., 2023b). The leaves of ferns are also classified as simple and still need to be in the form of strands (Anggraini et al., 2023). Ulfa, et al. (2023a) also explained that, in general, the leaves of ferns can be classified into two categories based on their size, namely large macrophil leaves and small microfil leaves, usually in the form of scales. The results of identifying the leaf morphology of ferns also show that most fern leaf morphology is in the form of sterile leaves, evidenced by the absence of sorus on the edge or bottom of the leaf. In addition, the tip of the leaf also rolls at a young age. Young leaves of fern plants have characteristics where the leaves form rolls and do not produce spores (Lestari & Indriyani, 2023; Ridhwan et al., 2023). Sterile leaves indicate that the age of the fern is still young. However, there are identification results where fertile leaves are found in *Platycerium bifurcatum* species. *Platycerium bifurcatum* species grow by attaching to their host tree with brown rhizomes covered by many supporting leaves (Nafisah et al., 2023).

Most sori on ferns are located at the bottom of fertile leaves with a transverse position or on the edge of the leaf. This is by Pradipta et al. (2023), which states that most Polypodiopsida class ferns have the sorus's location and position on the leaf's lower surface. The location of the sorus against the leaf bone is a crucial trait in the classification of ferns (Naiym & Munir, 2024). Sorus is a characteristic of ferns because of its location in a grouped spore (Aulia et al., 2024). The results of morphological identification of rhizomes of ferns showed that overall rhizomes of ferns with hair of various sizes, ranging from long and short depending on the size of the ferns; besides the rhizomes of ferns, are also many creeping and creeping to attach to the host, such as *Drynaria sparsisora, Platycerium bifurcatum* and *Drynaria quercifolia*. This suggests that some ferns are epiphytes. *Drynaria quercifolia* species has scaly rhizomes resembling brown hair with large rhizome leaves and creeping (Afriana et al., 2021). *Drynaria quercifolia* species are also found attached to the trunk of oil palm plants with creeping stems and have ovoid supporting leaves that cover the roots and rhizomes (Jusri et al., 2022; Listiyanti et al., 2022). In addition, *Drynaria quercifolia* species have sorus in the form of brown round dots scattered on the lower surface of the leaves (Tnunay & Hanas, 2020).

Identification of Pterydophyta Diversity Index

Table 5 presents the results of the analysis related to the diversity index in each fern species found in the Tuban-Lamongan Pantura area.

Table 5. Diversity index of each species

Species Name	ni	pi $\left(\frac{ni}{N}\right)$	$\ln pi$	pi $\ln pi$
Adiantum capillus-veneris	44	0.21	-1.57	-0.33
Pteris vittata	78	0.37	-1.00	-0.37
Pellaea viridis	1	0.00	-5.35	-0.03
Elaphoglossum stenoglossum	2	0.01	-4.66	-0.04
Helminthostachys zeylanica	4	0.02	-3.97	-0.08
Drynaria sparsisora	17	0.08	-2.52	-0.20
Platycerium bifurcatum	9	0.04	-3.15	-0.13
Pellaea atropurpurea	2	0.01	-4.66	-0.04
Cheilanthes micropetris	5	0.02	-3.74	-0.09
Adiantum latifolium	1	0.00	-5.35	-0.03
Amblovenatum terminans	6	0.03	-3.56	-0.10
Asplenium pinnatifidum	16	0.08	-2.58	-0.20
Drynaria quercifolia	5	0.02	-3.74	-0.09
Christella dentate	1	0.00	-5.35	-0.03
Drynaria fortune	3	0.01	-4.25	-0.06
Botrychium jenmanii	6	0.03	-3.56	-0.10
Asplenium trichomanes	3	0.01	-4.25	-0.06
Microsorum pustulatum	3	0.01	-4.25	-0.06
Oleandra distenta	4	0.02	-3.97	-0.08
Total	210	1.00	-71.48	2.10

Based on the data analysis in Table 5. it is known that the fern diversity index in the Pantura Tuban-Lamongan area obtained a result of H'=2.10. which is classified as in the medium category with the criteria 1≤H'≤3 with a total of 19 types of species and a total of 210 individuals. In Laeto & Taharu (2021) it is explained that the moderate diversity index shows that the number of species among the total number of individuals of all existing species is moderate, meaning that the ratio of the number of individuals of a species to the total number of individuals of all species is moderate. The diversity index value is relatively high, considering the Tuban-Lamongan coastal area has high air temperature and light intensity. In addition, the number of individuals of each species also varies and has an uneven distribution pattern. The acquisition of the number of individuals of each different species is due to several abiotic factors that influence it, such as soil pH and air temperature (Zhang et al., 2021). This is in accordance with the results of research by Liu et al. (2021), which states that functional richness, maximum air temperature, soil pH, and their interactions show a strong influence on species diversity. Based on the diversity index value obtained also shows that the existing fern species community is relatively stable, as evidenced by the diversity index value obtained, which is classified as medium. This is considering that the higher the diversity index value, the more stable the existing species community (Inama et al., 2023; Leki et al., 2022). In addition, the high and low diversity index of a plant community depends on the number of species, individuals of each type, and existing environmental factors (Ballo et al., 2024; Windari et al., 2021). If the number of identified species increases, the diversity index will increase. However, conversely, if the number of identified species is only small, then the diversity index will be low (Yolla et al., 2022).The fern species with the highest diversity value is *Pteris vittata*, 0.37. Meanwhile, the fern species with the lowest diversity values are *Elaphoglossum stenoglossum, Adiantum latifolium*, and *Christella dentata*. The *Christella dentata* species is usually found in soil near water sources (Puspa et al., 2023). This is because there is only one individual in each of the three species of ferns. Ferns can spread quickly and form a diversity that can be identified based on morphological characteristics. The diversity in question is the richness of fern species found in an area (Adlini et al., 2021).

Analysis of Potential Research Results in Support of FBP

The results of research that has been carried out regarding morphology-based Pterydophyta diversity in the Pantura Tuban-Lamongan area can potentially be used in the world of education to support the implementation of FBP in Low plant botany courses for biology education students with the contribution of providing knowledge and understanding of morphology-based Pterydophyta diversity learning materials comprehensively, directly through experience and application of theories and research methods used in everyday life.

FBP is one of the activities in Project Learning (PjBL) courses that aim to make students independent through direct learning in nature, the field, or the community (Nurdiansyah, 2023). FBP plays a role in students integrating and applying knowledge values into practice in a complex manner involving several skills (Arundel et al., 2022). Matsna et al. (2023) explained that the application of FBP can improve students' Science Process Skills (KPS) by allowing students to experience or do it themselves and be able to determine problems, observe, analyze, hypothesize, conclude, and apply the theories they have according to their needs, apart from that FBP It is also able to arouse learning motivation and encourage students' curiosity so that these principles will support students to discover their knowledge through field exploration. Therefore, FBP is widely applied to support students in determining the effectiveness of ongoing learning (Petra et al., 2020; Tedam et al., 2021).

PjBL-based FBP has been applied in learning activities for students, and the results of the learning process show positive changes in students because students experience themselves actively in their activities. Student activities through FBP on morphology-based Pterydophyta diversity can increase student knowledge, understanding, learning outcomes, motivation, and critical thinking skills. This is in accordance with the results of research by Aleman et al. (2021) which states that students who use field-based practicum show a positive increase in the benefits, value and student engagement with learning. Pratomo & Nur (2024) added that field practicum activities are an effort to broaden cognitive insights while honing students' psychomotor abilities. In addition, Alamri (2018) stated that practicum problems are a big critical concern and essential to learning. FBP is an innovation in learning considering that practicum in the laboratory has several serious concerns, including classroom management, non-existent laboratory space, lack of tools and materials, teacher training on laboratory management is very lacking, practicum duration, lack of teacher regulations and experience, and inefficient feedback (Bahtiar et al., 2022).

The application of FBP in Low plant botany courses for biology education students regarding morphology-based Pterydophyta diversity in the Pantura Tuban-Lamongan area requires further research with developing field-based practical instructions.

Conclusion

Based on the research results, we conclude that the level of fern diversity in the Pantura Tuban-Lamongan area is classified as medium with diverse morphological characteristics. The results of the research that has been carried out have the potential to be used in the world of education to support field-based practicums in Low plant botany courses with the contribution of providing direct knowledge and experience regarding the diversity of ferns in the surrounding environment.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Author Contributions

Y. Yudhistian: data analysis, methodology, writing original draft preparation, observation and sampling; and **T. S. H. Wulandari:** review and editing.

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