

COMPOSITION, COMMUNITY STRUCTURE AND VERTICAL DISTRIBUTION OF EPIPHYTIC FERNS ON BAMBOO SPECIES IN BOGOR BOTANIC GARDENS, INDONESIA

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Abstract

Ecological study of epiphytic ferns growing on bamboo species in Bogor Botanic Gardens, a man-made ecosystem located in a wet lowland area was carried out. The 350 phorophytes of 35 bamboo clumps belonging to 9 species and 3 genera were observed. Each culm was divided into intervals of 1 m from ground level to a height of 3 m. A total of 1984 individuals belonging to 12 species, nine genera, and six families of epiphytic ferns were recorded, with the highest species richness in Polypodiaceae (7 spp.). *Dendocalamus giganteus* Munro was the best host for epiphytic ferns (9 spp.). Two dominant species, *Asplenium nidus* L. and *Davallia denticulata* (Burm.f.) Mett. ex Kuhn with the same frequency value (97.14%), and relative species abundance of 31.49 individuals per clump and 14.94 individuals per clump, showed the highest Importance Value Index (IVI) of 83.19 and 54.00%, respectively. The first one-meter level of bamboo culms hosted all the species. *Pyrrosia piloselloides* (L.) Price was the only species that grew until the highest intervals of height with a decreasing frequency from the bottom.

Introduction

Epiphytes are vascular and non-vascular plants that live on other plants, but they do not gain nutrient or water supply directly from the host (Kress 1986). Some species of epiphytic plants play a very important role in biogeochemical processes, provide favorable microsites for free-living nitrogen-fixing bacteria (Brighicna *et al.* 1992), increase the retention of water derived from precipitation (Veneklaas and Van Ek 1990), contribute to primary productivity, litterfall, and nutrient cycling due to their high growth efficiency, including leaf production and root growth (Putz 1983).

Epiphytic plants comprise about 10% of all vascular plants and are particularly abundant and diverse in the wet tropics. These epiphytic plants are mainly distributed within angiosperms and ferns. A total of 2,593 epiphytic species of 92 genera of ferns and fern-allies were recorded in the world (Nieder *et al.* 2001). However, the ecology of many epiphytic species is poorly understood especially in the wet tropic regions (Adubasim *et al.* 2018). In addition, presently most studies on the ecology, floristic, and diversity of epiphytic ferns were reported from Brazil (Machado *et al.* 2016), Mexico (Jiménez-López *et al.* 2020), French Polynesia (Nitta *et al.* 2020), and Peninsular Malaysia (Zhang *et al.* 2010). Studies dealing with the assessment of host variability and their composition for epiphytic ferns have been reported everywhere. Epiphytic ferns can inhabit a wide variety of flowering trees and tree ferns (Einzmann *et al.* 2015, Parashurama *et al.* 2016). However, an epiphytic symbiosis between ferns and bamboo has not been reported yet either in the natural and man-made ecosystem, such as botanic gardens.

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Bamboo has unique features that distinguish it from most other woody plants. Bamboo culms are connected by an extensive system of rhizomes leading to emerging new culms by rapid vegetative reproduction (Jansen 1976). Bamboos are included in the fastest-growing plants in the world and tolerance for marginal land, therefore bamboo is a good candidate for afforestation and in mitigating climate change impacts through carbon sequestration (Terefe *et al.* 2019). Bamboo culms may have the potential to be an epiphyte host species for ferns in the wet tropical forests although they have no bark as on the other tree plants. Many species of bamboo may give rise thick aerial roots at lower nodal region creating microhabitat for epiphytic ferns.

The present study aimed to figure out the floristic composition, community structure, and vertical distribution of epiphytic ferns on bamboo species in the Bogor Botanic Gardens. This is the first report on the ecological study of epiphytic ferns growing on bamboo species in the Gardens. This research was conducted in order to answer three questions, i.e. (i) how do species richness and composition of ferns epiphytes vary over host bamboo culms? (ii) how do these species' richness and composition patterns correlate with host characteristics and environmental factors? and (iii) how do ferns epiphytes distribute vertically over host bamboo culms?

Materials and Methods

The present study was conducted from December 2020 to April 2021 in Bogor Botanic Gardens (BBG), Indonesia (Fig. 1). The garden has maintained 12,370 specimens belonging to 3,555 species, 1,202 genera, and 191 families of vascular plants (Ariati *et al.* 2019). BBG is covering an area of 87 ha. at an altitude of 215-250 m asl. and topography is relatively flat with a slope of 3 - 15% and 16 - 31% near the river bank (Santosa *et al.* 2014). According to the Köppen climate classification (Köppen 1936), BBG climate belongs to the Wet Tropical Climate type (Af) with an average temperature of 26°C, the lowest and highest temperature is 21.4 and 30.4°C, respectively. The humidity is more than 70%, and the monthly rainfall ranges from 250-330 mm. The annual rainfall varies between 3000-5000 mm, with more than 240 rainy days and the highest rainfall occurs in December and January every year (Santosa *et al.* 2014).

Thirty-five bamboo clumps of 28-48 years old belonging to nine species of three genera planted in eight collection sites were surveyed (Fig. 1). The 10 sampled were culms for each clump purposively to count sporelings and sporophytes of the epiphytic ferns. Epiphytic ferns were recorded from the basal culms to a height of 3 m. Each culm was divided into intervals of 1 m from ground level to a height of 3 m, thus obtaining 1050 one-meter samples of the epiphytic fern community on culms stratified according to height. The species determination methods of Holttum (1966) and Hovenkamp *et al.* (1998) were followed. To ensure accurate species identification for sporelings of the epiphytes, only sporelings with the minimal sizes of ca.10 mm length and ca.5 mm wide were recorded (Fig. 2). Definition for epiphytic classification followed Zotz (2016), whereas the classification system followed Smith *et al.* (2008).

Host culm height and diameter at breast height (dbh) were recorded using a digital forestry range finder (Nikon Forestry Pro Waterproof 6 × 12 6.0°) and diameter tape, respectively. Other characteristics and environmental variables measured at each bamboo clumps were the numbers of bamboo reeds/clumps, temperature, humidity, light intensity, canopy cover, and direction overgrown. Canopy covers and direction overgrown were estimated using Canopy Cover Free using android device's camera and Compass of Google Play Applications, respectively,

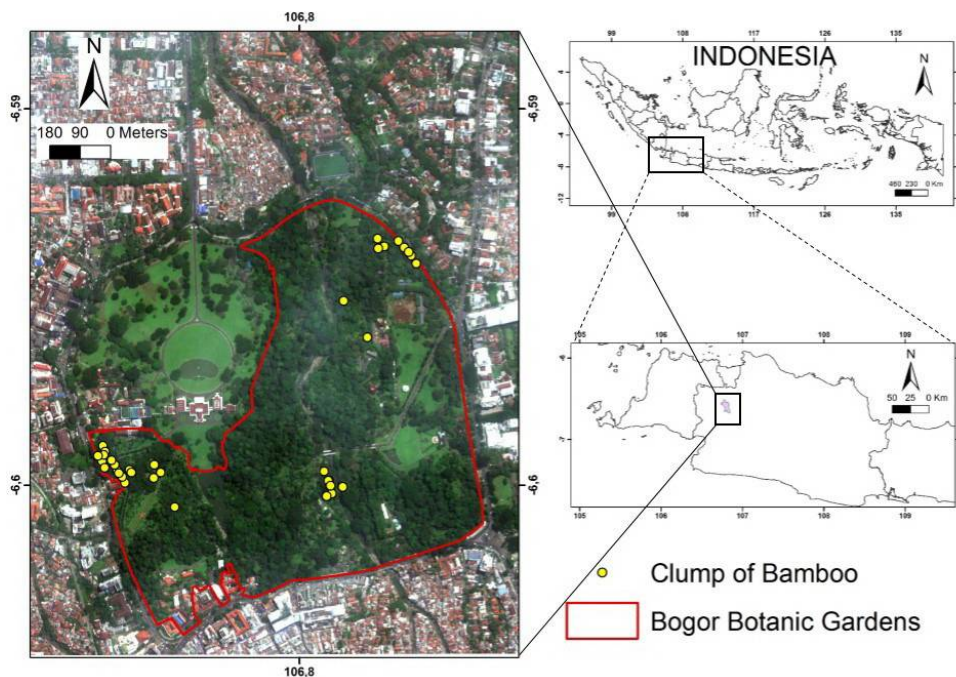


Fig. 1. Map of Bogor Botanic Gardens. Yellow circles are showing eight locations of the 35 clumps belonging to 9 bamboo species observed.

The fern vegetation data were analyzed quantitatively, by abundance, frequency, relative density, relative frequency, and Important Value Index (IVI) (Curtis and McIntosh 1950) by the following equation:

$$\text{Relative Density} = \frac{\text{Number of individuals of species}}{\text{Total number of individuals of all species}} \times 100$$

$$\text{Relative Frequency} = \frac{\text{Frequency of species}}{\text{Sum of frequency values for all species}} \times 100$$

The IVI was calculated by adding the relative density and relative frequency values. Analysis of the diversity of epiphytic ferns growing on bamboo using several diversity indices, namely Margalef richness index (D_{mg}), Shannon diversity index (H'), and Buzas and Gibson's evenness index (E) with the following equation:

$$D_{mg} = \frac{S - 1}{\ln N}$$

$$H' = - \sum_{i=1}^m \left[\left(\frac{n_i}{N} \right) \ln \left(\frac{n_i}{N} \right) \right]$$

$$E = \frac{e^{H'}}{S}$$

Where: D_{mg} = Margalef richness index, N = Total number of individuals of all species, S = Number of all species, H' = Shannon diversity index, n_i = Number of individuals of each species,

E = Buzas and Gibson's evenness index, e =Natural logarithm base (Buzas and Gibson 1969, Magurran 2004).

Variations of fern abundance, diversity indices, and environmental variables in each bamboo clump were analyzed after using Analysis of Variance (ANOVA). For significantly different variables, it was followed by Duncan's multiple range test (DMRT). Ordination analysis was used to determine the relationship between the abundance of epiphytic ferns and environmental variables using Canonical Correspondence Analysis (CCA). Diversity index analysis, analysis of variance, and Canonical Correspondence Analysis were calculated using Paleontological Statistics (PAST) version 3.26 (Hammer *et al.* 2001).

Results and Discussion

A total of 1984 individuals belonging to 12 epiphytic fern species under eight genera and six families were recorded (Fig. 2 and Table 1). The floristic composition of the epiphyte community is similar to those found on palm trees growing in BBG with 16 species of epiphytic ferns and lycophytes (Praptosuwiryo *et al.* 2019). The highest species richness was recorded in Polypodiaceae with seven species. The dominance of the Polypodiaceae is a common trend in wet tropical epiphyte communities.

Previous publications stated that the epiphytic ferns flora holo-epiphytes are usually predominant (Fraga *et al.* 2008 and Schneider and Schmitt 2011) in Brazil; and Praptosuwiryo *et al.* (2019) in BBG. Some epiphytes also grow occasionally on rocks, such as *Belvisia mucronata* and *Microsorium scolopendria* (Hovenkamp *et al.* 1998), or soil such as *Nephrolepis biserrata* (Xing *et al.* 2013) and *Psilotum nudum* (Zhang and Yatskievych 2013). *Pyrrhosia piloselloides* is also a facultative mild-hemiparasitic epiphyte (Tsutsumi *et al.* 2018).

Abundance is the average number of individuals of a species in an observation plot area (Curtis and McIntosh 1950). The abundance of ferns growing on bamboo clumps was 56.69 individuals/clump on average, with a range from 0.03 to 31.49 individuals per clump (Table 2.). *Asplenium nidus* and *D. denticulata* had the highest abundance, *viz.* 31.49 individuals per clump and 14.94 individuals per clump, respectively. Most of the species showed low abundance, such as *P. lanceolata*, *M. scolopendria*, *M. punctatum*, *P. nudum*, *G. percussum*, and *B. mucronata*.

The range of frequency values of epiphytic ferns growing on bamboo clumps species was 2.87 - 97.14% (Table 2). *Asplenium nidus* and *D. denticulata* had the highest frequency as the two species were found in 34 clumps of 35 bamboo clumps observed. Another species with the high frequency was *P. piloselloides*, it could be found growing well on 18 clumps. According to Dajoz (1977), *A. nidus*, *D. denticulata*, and *P. piloselloides* have a constant distribution in the study site ($50\% \leq F < 100\%$). *V. ensiformis* has a common distribution ($25\% \leq F < 50\%$), seven species come into the category a by-catch distribution ($5\% \leq F < 25\%$), and two species, namely *G. percussum* and *B. mucronata* have a rare distribution ($F < 5\%$).

The level of importance of a species in the community can be seen from the IVI value (Schneider and Schmitt 2011). Epiphytic fern species with the highest IVI was found in *A. nidus*, followed by *D. denticulata*, *P. piloselloides*, and *Vittaria ensiformis* with IVI of 83.19, 54.00, 21.04 and 16.66%, respectively. These three species have a high density and are evenly distributed over various species of bamboo clumps. Other eight species of ferns have low IVI (<10%) (Table 2.). This indicated that the role of these species in the fern community of the bamboo clumps is low. They generally have a low density and were only found in certain bamboo clump habitats. Species that have a low IVI need more concrete conservation efforts for these species to be sustainable.

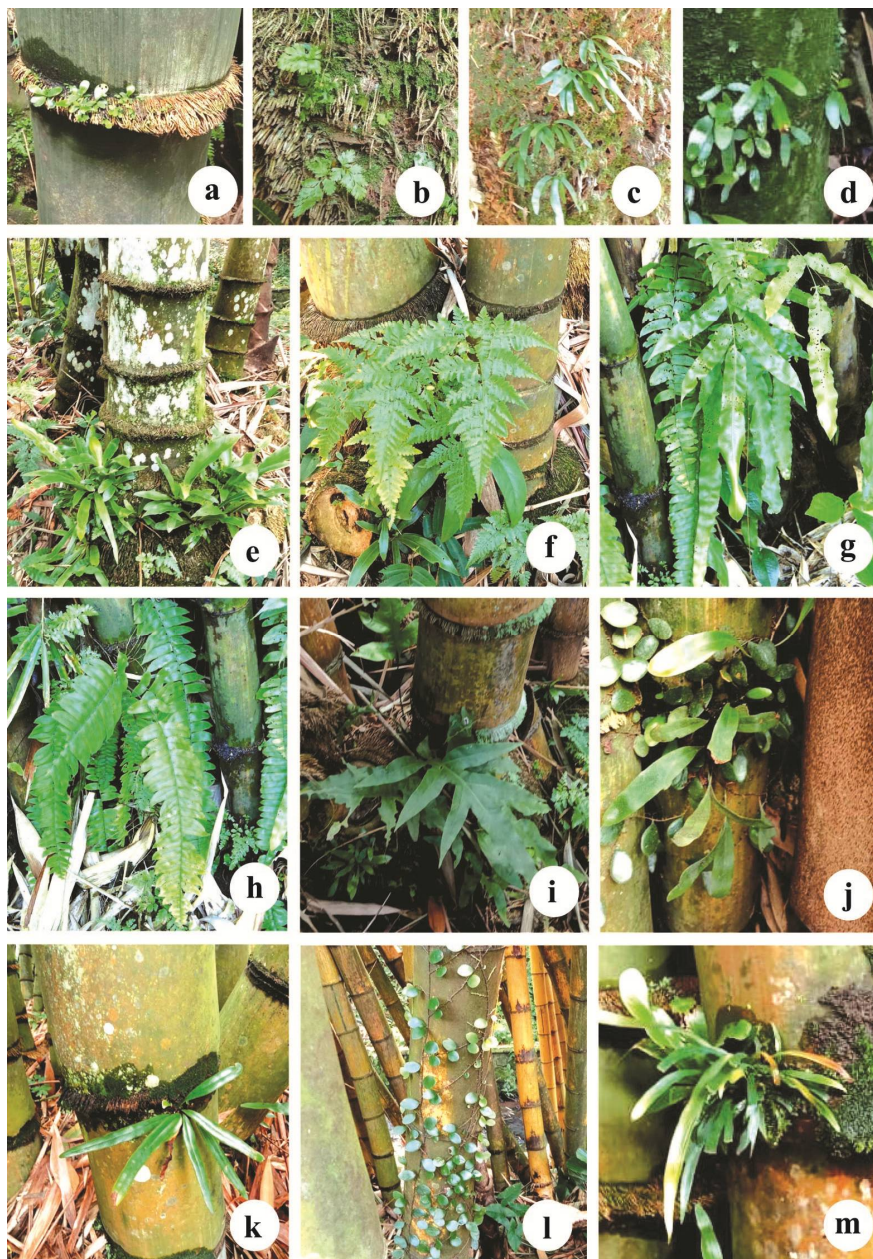


Fig. 2. Ferns epiphyte growing on bamboo culms in Bogor Botanic Gardens. a – d. Sporelings of epiphytic ferns. a. *Asplenium nidus* on the node of *Dendrocalamus giganteus*; b-c. *Davallia denticulata* and *Vittaria ensiformis*, respectively, perching on aerial roots of *D. asper*; d. *Pyrrosia longifolia* on the internode of *D. asper*. e – m. Young sporophytes. e. *A. nidus* on the aerial roots of *D. asper*; f. *Davallia denticulata* on aerial roots of *D. giganteus*; g-h *Goniophlebium percussum* and *Nephrolepis biserrata* on node and internode of *Gigantochloa apus*, respectively; i. *Microsorium punctatum* on the aerial root of *D. giganteus*; j. *Pyrrosia lanceolata* on the node and internode of *G. atter*; k. *Pyrrosia longifolia* on the node of *D. giganteus*; l. *Pyrrosia piloselloides* on the internode of *Bambusa vulgaris*; m. *Vittaria ensiformis* on the node of *D. giganteus*.

Table 1. Floristic composition, lifeform, habitat, perching site, and host plants of epiphytic ferns growing on bamboo culms species planted in Bogor Botanic Gardens.

No.	Family and species	Lifeform /rhizome	Ecological category	Perching sites	Σ Individual	Host plants
1.	Aspleniaceae <i>Asplenium nidus</i> L.	Short upright	HAB	RB, ND	1102	(1), (2), (3), (4), (5), (6), (7), (8), (9)
Davalliaceae						
2.	<i>Davallia denticulata</i> (Burm.) Mett. ex Kuhn	Long creeping	HAB	RB, ND	523	1), (2), (3), (4), (5), (6), (7), (8), (9)
Nephrolepidaceae						
3.	<i>Nephrolepis biserrata</i> (Sw.) Schott	Long creeping	HMP	RB, ND	32	(3), (4), (6), (8)
Polypodiaceae						
4.	<i>Belvisia mucronata</i> (Fée) Copel.	Short creeping	HAB	ND	1	(4)
5.	<i>Goniophlebium percussum</i> (Cav.) Wagner & Grether	Long creeping	HAB	RB, ND	3	(6)
6.	<i>Microsorium scolopendria</i> (Burm. f.) Copel.	Long creeping	HAB	RB	9	(2), (4)
7.	<i>Microsorium punctatum</i> (L.) Copel.	Short creeping	HAB	RB, ND	9	(2)
8.	<i>Pyrrosia lanceolata</i> (L.) Farw.	Long creeping	HAB	ND, IN	9	(2), (5), (6), (7)
9.	<i>Pyrrosia longifolia</i> (N. L. Burman) Morton	Long creeping	HAB	ND	27	(2), (4), (8)
10.	<i>Pyrrosia piloselloides</i> (L.) Price	Long creeping	HAB	RB, ND, IN	127	1), (2), (3), (4), (5), (7), (8), (9)
11.	Psilotaceae <i>Psilotum nudum</i> (L.) Pal. Beauv.	Short-to long creeping,	FAC	RB	5	(4)
Pteridaceae						
12.	<i>Vittaria ensiformis</i> Swartz.	Short-creeping	HAB	RB/ND/IN	137	(2), (3), (4), (5), (8)
Total 12 species; 9 genera; 6 families					1984	

Host plants: (1) *Bambusa vulgaris* Schrad.; (2) *Dendrocalamus asper* (Schult.) Backer; (3) *Dendrocalamus brandisii* (Munro) Kurz; (4) *Dendrocalamus giganteus* Munro; (5) *Dendrocalamus latiflorus* Munro; (6) *Gigantochloa apus* (Schult.) Kurz; (7) *Gigantochloa atter* (Hassk.) Kurz; (8) *Gigantochloa robusta* Kurz.; (9) *Gigantochloa verticillata* (Willd.) Munro. HAB = habitual holoeiphytes; FAC = facultative holoeiphytes; HMP = Primary emieiphytes; Perching Site: RB= Aerial roots of basal culm, ND= nodus, IN= internodes.

Table 2. Community structure of epiphytic ferns sampled on bamboo species in Bogor Botanic Gardens, West Java, Indonesia, in decreasing order by Value Index (IVI). D = Density (Individuals/Clump); F = Frequency; RD = Relative Density; RF = Relative Frequency; IVI = Important Value Index.

No	Species	D (indv./clump)	F (%)	RD (%)	RF (%)	IVI (%)
1	<i>Asplenium nidus</i> L.	31.49	97.14	55.54	27.64	83.19
2	<i>Davallia denticulata</i> (Burm.) Mett. ex Kuhn	14.94	97.14	26.36	27.64	54.00
3	<i>Pyrrosia piloselloides</i> (L.) Price	3.63	51.43	6.40	14.63	21.04
4	<i>Vittaria ensiformis</i> Swartz.	3.91	34.29	6.91	9.76	16.66
5	<i>Nephrolepis biserrata</i> (Sw.) Schott	0.91	22.86	1.61	6.50	8.12
6	<i>Pyrrosia longifolia</i> (N. L. Burman) Morton	0.77	11.43	1.36	3.25	4.61
7	<i>Pyrrosia lanceolata</i> (L.) Farw.	0.26	11.43	0.45	3.25	3.71
8	<i>Microsorium scolopendria</i> (Burm. f.) Copel.	0.26	8.57	0.45	2.44	2.89
9	<i>Microsorium punctatum</i> (L.) Copel.	0.26	5.71	0.45	1.63	2.08
10	<i>Psilotum nudum</i> (L.) Pal. Beauv.	0.14	5.71	0.25	1.63	1.88
11	<i>Goniophlebium percussum</i> (Cav.) Wagner & Grether	0.09	2.86	0.15	0.81	0.96
12	<i>Belvisia mucronata</i> (Fée) Copel.	0.03	2.86	0.05	0.81	0.86

The Abundance of some species and diversity indices in each bamboo clump have varying values (Table 3). The one-way ANOVA test revealed that the abundance, number of species, richness, diversity and evenness index of ferns among the nine bamboo clumps were not significantly different ($P > 0.05$). Based on the number of epiphytic fern species growing in the bamboo clumps, the highest occurred on *Dendrocalamus giganteus* clump with an average of 4.13 ± 1.25 species, meanwhile, *Gigantochloa verticillata* clump had the lowest with an average 2.33 ± 0.58 species.

Dendrocalamus brandisii and *D. giganteus* clumps displayed the greatest abundance of epiphytic ferns with values of 120.50 ± 53.03 and 82.75 ± 63.08 individuals/clump, respectively, while their species richness was relatively even. The lowest epiphytic fern abundance occurred on *Gigantochloa apus* clumps with an abundance value of 19.40 ± 20.22 individuals/clump. The high abundance of ferns in *D. brandisii* is probably due to the characteristic factors of the bamboo. *Dendrocalamus brandisii* has stems that are smooth, straight, without spines, and a trunk height of about 25-30 m with a diameter of 13-30 cm (Viswanath *et al.* 2013). This study revealed that *D. brandisii* has the highest number of culms per clump compared to other species, of 186.50 ± 37.48 culms per clump with an average culm height of 19.65 ± 1.77 m and 13.49 ± 2.38 cm in diameter. The high number of culms in one clump causes a large amount of water to be trapped in the bamboo culms, roots, and rhizomes. This resulted in fairly high water availability in the bamboo clumps which supported spore germination and the growth of ferns. Ferns are very sensitive to water availability and drought (Benzing 1998). A large number of culm also represents more habitat partitioning and more available space for spore interception, colonization, and biomass development. These results are in line with the widely documented dependence of epiphyte proliferation on tree size (Zotz and Vollrath 2003).

Table 3. Abundance, number of species, and diversity indices of epiphytic ferns community sampled on bamboo clumps in Bogor Botanic Gardens.

No.	Bamboo clumps	A	S	D _{mg}	H'	E
1	<i>Bambusa vulgaris</i> Schrad.	35.50±19.09	2.50±0.71	0.41±0.14	0.63±0.64	0.79±0.28
2	<i>Dendrocalamus asper</i> (Schult.) Backer	78.00±54.08	3.86±1.46	0.68±0.28	0.87±0.42	0.67±0.06
3	<i>Dendrocalamus brandisii</i> (Munro) Kurz	120.50±53.03	4.00±0.00	0.64±0.06	0.96±0.32	0.67±0.21
4	<i>Dendrocalamus giganteus</i> Munro	82.75±63.08	4.13±1.25	0.74±0.26	0.86±0.51	0.63±0.18
5	<i>Dendrocalamus latiflorus</i> Munro	42.33±12.66	4.00±1.73	0.79±0.41	1.03±0.34	0.75±0.10
6	<i>Gigantochloa apus</i> (Schult.) Kurz	19.40±20.22	3.20±1.79	0.81±0.34	0.74±0.44	0.74±0.12
7	<i>Gigantochloa atter</i> (Hassk.) Kurz	37.00±26.87	3.00±1.41	0.64±0.55	0.87±0.36	0.84±0.11
8	<i>Gigantochloa robusta</i> Kurz.	24.33±20.21	3.00±1.00	0.67±0.11	0.77±0.31	0.75±0.03
9	<i>Gigantochloa verticillata</i> (Willd.) Munro	29.67±31.00	2.33±0.58	0.45±0.08	0.60±0.22	0.80±0.05
	<i>P Value</i>	0.108	0.539	0.675	0.956	0.387

A = Abundance (indv./clump); S = Number of species; D_{mg} = Margalef's richness index; H' = Shannon's diversity index; E = Buzas and Gibson's evenness index.

The abundance of epiphytic species has a positive correlation with DBH of host species, where an increase in DBH of host species will increase the availability of space for the epiphyte plants to attach and grow (Magalhães and Lopes 2015). In this study, *D. brandisii* has the second highest culm diameter after *D. giganteus*. The larger diameter of the bamboo culms allows more space for the interception and germination of spores, as well as the colonization of the sporophyte of epiphytic ferns.

Margalef's richness index of ferns growing in bamboo clumps has an average value of 0.41-0.81. Based on the species richness categories of Magurran (2004), it was concluded that the species richness of epiphytic ferns growing on bamboo clumps was classified into low richness. The value of the Shannon's diversity index on nine species of bamboo clumps was an average of 0.60-1.03. The value of Shannon's diversity index based on category by Schneider and Schmitt (2011) fern diversity in bamboo clumps is mostly included in the low category ($0 < H' < 1$) and only one location has a moderate diversity ($1 < H' < 3$). The low value of Margalef's richness and Shannon's diversity is because only a few ferns can live attached to bamboo clumps and bamboo is a specific habitat, so not all ferns can grow in that habitat. The low value of richness and diversity indicates that the fern community in the bamboo clump is unstable and susceptible to disturbance.

Buzas and Gibson's evenness analysis of ferns growing in bamboo clumps resulted in an average value of 0.63 - 0.84. The evenness of epiphytic ferns on bamboo species came into a high evenness ($E \geq 0.6$). A high evenness value indicates that the number of individuals in each species of ferns tends to be evenly distributed or there is no species of fern that dominates in the bamboo clump habitat, although there are some species of fern with a high abundance compared to the other species.

The one-way ANOVA test showed that the variables of temperature, humidity, canopy cover, and direction of growth where the epiphytic plants were perched on were not significantly different. Meanwhile, the parameters of height, diameter, number of culms, and light intensity differed significantly between bamboo clumps. Therefore, these parameters were used in the CCA.

Epiphytic ferns tend to inhabit the bamboo clumps with a range size of culms of 14.49-26.26 m height and 7.91-17.24 cm diam., 47.14-186.50 culms per clump, and providing a canopy opening for the light intensity range of 470.17-7113.00 lux (Table 4, Fig. 3).

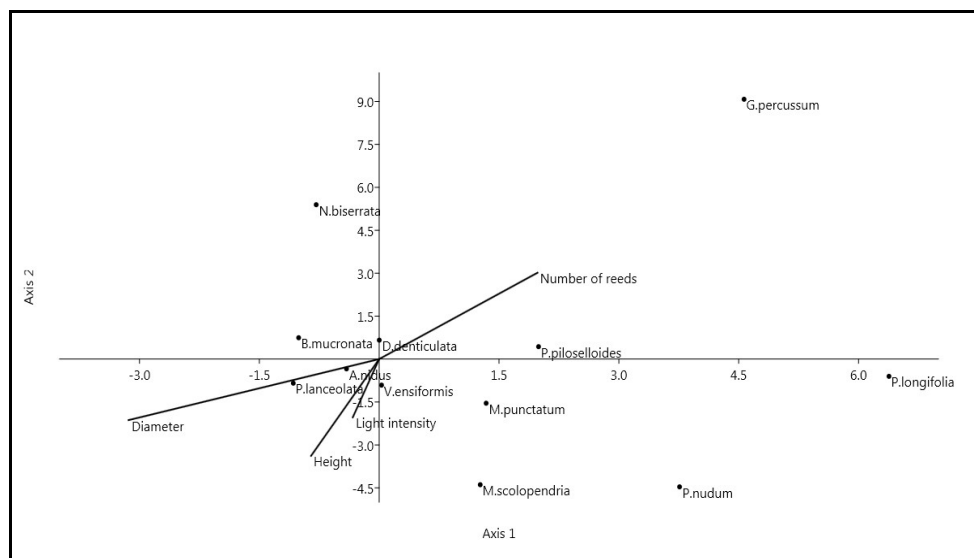


Fig. 3. Ordination diagram for Canonical Correspondence. Analysis of the abundance of fern and environmental variables.

Table 4. Characteristics of bamboo clumps and environmental variables for the epiphytic fern community in the Bogor Botanic Gardens.

No.	Bamboo clumps	Height (m)	Diameter (cm)	Number of reeds/culms	Temperature (°C)	Humidity (%)
1	<i>Bambusa vulgaris</i> Schrad.	14.49±1.07 ^a	8.70±1.34 ^a	166.00±114.55 ^{bc}	29.10±1.98	68.55±7.14
2	<i>Dendrocalamus asper</i> (Schult.) Backer	18.75±3.92 ^{ab}	12.60±2.48 ^{abc}	47.14±24.53 ^a	25.60±4.63	78.78±3.77
3	<i>Dendrocalamus brandisii</i> (Munro) Kurz	19.65±1.77 ^{ab}	13.49±2.38 ^{abc}	186.50±37.48 ^c	27.28±0.53	74.87±0.47
4	<i>Dendrocalamus giganteus</i> Munro	26.26±7.09 ^b	16.14±1.51 ^{bc}	128.75±56.89 ^{bc}	27.01±0.71	77.53±3.31
5	<i>Dendrocalamus latiflorus</i> Munro	22.48±7.75 ^{ab}	12.96±1.59 ^{abc}	59.67±28.36 ^a	29.37±2.15	71.60±8.47
6	<i>Gigantochloa apus</i> (Schult.) Kurz	16.92±2.19 ^{ab}	7.91±1.55 ^a	171.00±63.97 ^{bc}	27.73±1.42	78.48±4.87
7	<i>Gigantochloa atter</i> (Hassk.) Kurz	16.79±2.38 ^{ab}	7.91±0.28 ^a	84.50±58.69 ^{ab}	27.80±0.14	77.25±4.73
8	<i>Gigantochloa robusta</i> Kurz.	23.70±6.52 ^{ab}	10.42±0.50 ^{ab}	65.33±35.57 ^a	27.23±0.46	72.18±5.59
9	<i>Gigantochloa verticillata</i> (Willd.) Munro	23.02±2.17 ^{ab}	17.24±9.40 ^c	116.33±37.02 ^{abc}	29.37±3.70	73.88±17.42
P Value		0.045	0.001	0.004	0.484	0.493

Contd.

No.	Bamboo clumps	Light intensity (lux)	Canopy cover (%)	Direction overgrown (^o)
1	<i>Bambusa vulgaris</i> Schrad.	7113.00±8751.86 ^b	41.67±5.99	175.00±155.56
2	<i>Dendrocalamus asper</i> (Schult.) Backer	1121.09±908.74 ^a	45.56±4.56	167.86±33.39
3	<i>Dendrocalamus brandisii</i> (Munro) Kurz	700.50±453.26 ^a	49.54±0.96	109.50±28.99
4	<i>Dendrocalamus giganteus</i> Munro	1616.31±1642.78 ^a	39.77±14.72	157.38±73.84
5	<i>Dendrocalamus latiflorus</i> Munro	470.17±373.59 ^a	39.51±26.56	171.00±59.19
6	<i>Gigantochloa apus</i> (Schult.) Kurz	863.10±1019.10 ^a	46.19±11.62	129.40±63.44
7	<i>Gigantochloa atter</i> (Hassk.) Kurz	511.88±331.81 ^a	34.75±17.15	149.50±99.70
8	<i>Gigantochloa robusta</i> Kurz.	689.83±277.05 ^a	52.49±7.10	220.00±84.00
9	<i>Gigantochloa verticillata</i> (Willd.) Munro	609.83±404.38 ^a	36.60±5.72	192.83±79.11
	<i>P Value</i>	0.038	0.710	0.747

Different lowercase letters indicate a significant difference between bamboo clumps using Duncan's multiple range test in ANOVA at 95% confidence interval.

The CCA resulted 4 axes, in which the combination of the two main axes is able to explain the relationship between the abundance of ferns and environmental variables of 84.74% of the total variance, with the proportion value of axis 1 and axis 2 of 47.55% and 37.19%, respectively. The ordination chart showed that *A. nidus*, *D. denticulata* and *V. ensiformis* commonly found in bamboo clumps were located near the center of ordination, so that these species are able to grow and adapt to the different habitat conditions. *A. nidus* is generally be found in bamboo clumps with a large diameter, high number of culm, and high light intensity. *Davallia denticulata* tends to inhabit bamboo clumps which have a high number of culms with low culm height and low light intensity. *Pyrrosia piloselloides* tend to be fond of bamboo clumps with a low culm diameter and a high number of culms. The epiphytic fern that is rarely found, *Goniophlebium percussum*, has a strong correlation with the number of bamboo culms.

On the bamboo clumps, *A. nidus*, *D. denticulata*, and *V. ensiformis* are usually to be more perched on the aerial roots of basal culms. The larger the dbh diameter the wider the available aerial roots available. The wider the aerial roots, the greater the chance for the spores to perch on. These findings are consistent with the work of Zhang et al (2010), that the distribution of *A. nidus* within the forest is largely determined by moisture availability. The aerial roots of basal bamboo culms which are closer to the ground provide a more humid micro-habitat for *A. nidus*, *D. denticulata*, and *V. ensiformis*. A previous study has shown that *A. nidus* growth is more affected by water stress (Ainuddin and Najwa 2009). On palm trees, *D. denticulata* and *V. ensiformis* grow well and make dense populations in the basal zone (Praptosuwiryo *et al.* 2019).

The analysis of the abundance of ferns on the vertical gradient showed that the abundance of epiphytic ferns on the dominant bamboo is on the first interval (0-1 m) with an average value of 55.63 individuals/bamboo clumps or 98.14% of the entire fern population found. Meanwhile, the vertical gradient level 2 (1-2 m) and level 3 (2 -3 m) only have an abundance of less than one individual/bamboo clump. Results of the one-way ANOVA test showed that the abundance of ferns at several vertical gradients was significantly different ($P < 0.01$), while based on the DMRT test, it was found that the abundance of ferns at level 1 was different from the abundance of level 2 and level 3 (Table 5).

The first one-meter intervals of bamboo culms hosted all species of the epiphytic ferns. Three species, namely *P. longifolia*, *D. denticulata* and *A. nidus* were found only up to 2 m high. *P. piloselloides* and *M. punctatum* can grow at a vertical gradient up to level 3. The results of the study are in agreement with the work of Magalhães and Lopes (2015) in tropical forests of Brazil, species of the Aspleniaceae, Lomariopsidaceae, and Pteridaceae that embellish trees are growing at a vertical gradient of 0 - 1.5 m, while the member from the Polypodiaceae was growing at a vertical gradient of 0 - 2.5 m. *Pyrrosia piloselloides* was the only species that grew until the highest intervals of height with a decreasing frequency from the bottom.

Table 5. Vertical distribution of epiphytic ferns growing on bamboo species.

Species	Abundance (indv./clump)			Percent (%)		
	Level 1	Level 2	Level 3	Level 1	Level 2	Level 3
<i>Asplenium nidus</i> L.	31.46	0.03	0.00	99.91	0.09	0.00
<i>Belvisia mucronata</i> (Fée) Copel.	0.03	0.00	0.00	100.00	0.00	0.00
<i>Davallia denticulata</i> (Burm.) Mett. ex Kuhn	14.77	0.17	0.00	98.85	1.15	0.00
<i>Goniophlebium percussum</i> (Cav.) Wagner & Grether	0.09	0.00	0.00	100.00	0.00	0.00
<i>Microsorium punctatum</i> (L.) Copel.	0.23	0.00	0.03	88.89	0.00	11.11
<i>Microsorium scolopendria</i> (Burm. f.) Copel.	0.26	0.00	0.00	100.00	0.00	0.00
<i>Nephrolepis biserrata</i> (Sw.) Schott	0.91	0.00	0.00	100.00	0.00	0.00
<i>Psilotum nudum</i> (L.) Pal. Beauv.	0.14	0.00	0.00	100.00	0.00	0.00
<i>Pyrrosia lanceolata</i> (L.) Farw.	0.26	0.00	0.00	100.00	0.00	0.00
<i>Pyrrosia longifolia</i> (N. L.)	0.51	0.26	0.00	66.67	33.33	0.00
<i>Pyrrosia piloselloides</i> (L.) Price	3.06	0.49	0.09	84.25	13.39	2.36
<i>Vittaria ensiformis</i> Swartz.	3.91	0.00	0.00	100.00	0.00	0.00
Sum	55.63^b	0.94^a	0.11^a	98.14^b	1.66^a	0.20^a

Different lowercase letters indicate a significant difference between bamboo clumps using Duncan's multiple rang test in ANOVA at 95% confidence interval.

The internodal surface texture of the bamboo is relatively smooth, but the aerial roots at nodes have a rough texture. The first interval from the basal bamboo has very dense aerial roots, so that the bottom texture is coarser than the vertical gradient above it. The coarser texture allows more spore capture and increasing the surface area for spore germination and gametophyte development. This observation showed that sporelings and young sporophytes were more often to be found at strata 1 (Fig. 2). It is indicated that the fern spores were much more trapped at the intervals 1. The environmental factor affecting the vertical distribution of the fern is wind. Wind gusts will affect the movement of the bamboo culms. The intensity of the bamboo movement is getting higher with increasing vertical gradient, as a result, the possibility of releasing spores from their attachments are getting higher.

The highest specific richness at the first interval might be also related to the strategies used by epiphytic ferns for standing in more humid conditions. The species with the highest frequency and importance value (*A. nidus*) had a decreasing occurrence percentage from the lowest to the second intervals of height. *P. piloselloides* was the only species that grew until the highest intervals of height with a decreasing frequency from the bottom of bamboo culms. *P. piloselloides* is drought resistant as it can grow extensively in dry season with elongation rate of rihizome 3.3 mm long per day (Tsutsumi *et al.* 2018). This species is one of the most common epiphytes in the Malesian lowlands, from sea level to 1000 m, that may overgrow entire tree and sometimes cause fatal

effects (Hovenkamp *et al.* 1998), therefore it can be included into a facultative mild-hemiparasitic epiphyte (Tsutsumi *et al.* 2018).

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