BRYOPHYTE DIVERSITY AND ATMOSPHERIC POLLUTION IN A RESIDENTIAL AREA AND AN INDUSTRIAL URBAN FOREST IN JAKARTA, INDONESIA

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ABSTRACT

Bryophytes are nonvascular plants that have simple structures that are sensitive to environmental changes, and they can, therefore be used as indicators of air quality. The presence of bryophytes in disturbed urban ecosystems, such as residential and industrial areas, indicates that their structures have adapted to survive in such areas. The objective of this study was to compare the bryophyte diversity and air quality indices between a residential area and an industrial area in Jakarta. The research was conducted in the Bona Indah residential area in South Jakarta and the Jakarta Industrial Estate Pulogadung (JEIP) urban forest. Sampling was carried out using the transect method in the residential area and the quadratic method in the urban forest on three different substrates, namely rocks or concrete, soil and tree trunks. The percentage of the epiphytic bryophyte cover was measured using a 10 × 10 cm subplot. Voucher specimens were stored at the Herbarium UI DEP and Herbarium IPB. Twenty-one species of moss and three species of liverwort were found in the two locations. Bryophytes were found on all the substrates in the residential area, but in the urban forest, they were found only on tree trunks and rock/cement substrates. Based on the Shannon–Wiener Index, although both locations had moderate bryophyte diversity, the residential area's bryophyte diversity was higher than that of the urban forest. The index of atmospheric purity in the residential area was 4.3, indicating a high level of pollution, and it was 0.3 in the urban forest, showing that it was also very polluted.

Keywords: atmospheric purity, bryophyte, diversity index, urban area

INTRODUCTION

An urban area is a region with high population density dominated by human activities such as trade, industry and education (Freedman 2018). Transportation and industry produce emissions such as carbon dioxide and nitrogen oxides that contribute to air pollution in urban areas. Pollution causes ecological effects such as the greenhouse effect, harm to plant and animal health and temperature stress (Kanawade *et al.* 2010). It is damaging to urban biodiversity because several species have become more sensitive to environmental stress from pollution and habitat fragmentation (Uttara *et al.* 2012; Szlavecs *et al.* 2011).

Jakarta is one of Indonesia's largest and most populous cities (Permatasari *et al.* 2019). According to worldpopulationreview.com, in 2023, its population was estimated at 11 million. The city's open green spaces have been reduced in area since 2008, leading to the urban heat island phenomenon (Putra *et al.* 2021). An industrial estate is a built-up area with relatively high pollution levels due to transportation and industrial combustion (Putra *et al.* 2021; Lestari *et al.* 2022), while residential areas consist of buildings and vegetation and have less air pollution than industrial areas (Putra *et al.* 2021). The air quality problem in Jakarta causes

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environmental stress, harming species sensitive to high temperatures, drought and air pollution, such as bryophytes (Oishi & Hiura 2017; Oishi 2019).

Bryophytes are non-vascular plants that are sensitive to environmental changes. The structure of bryophytes is simple; they have a thin cuticle layer so that water and minerals can be absorbed directly through the surface through diffusion. This causes the water content of bryophytes to depend on ambient humidity, making them poikilohydric. To survive in a dry environment, bryophytes develop some morphological adaptations for water retention and transportation (Vanderpoorten & Goffinet 2009; Proctor & Tuba 2002; Bahuguna *et al.* 2013; He *et al.* 2016). Based on these characteristics, bryophytes are suitable as air quality indicators, particularly in urban environments. Epiphytic species such as bryophytes and lichens are known to be drought-sensitive organisms. They have been reported to be absent in urban ecosystems, although certain species are known to be drought tolerant (Pescott *et al.* 2015; Bahuguna *et al.* 2013). This suggests that epiphytic bryophytes can be indicators of air quality through the index of atmospheric purity (IAP). Correlations between species distribution, IAP and pollutant concentrations can reflect the level of air pollution in a region (Jiang *et al.* 2020; Bahuguna *et al.* 2013).

Since the middle of the twentieth century, urban bryophyte-related air quality has been studied in subtropical regions, such as in European and Asian (Japan, China, India) countries and America and Australia. The study of air quality monitoring is carried out using a survey and a phytosociological approach, namely IAP, which was first used in 1970 by Le Blanc and Rao (Govindapyari *et al.* 2010). To show air quality, IAP is identified by the frequency and coverage of epiphytic bryophytes and the species resistance factor (Dymitrova 2009; Vanderporrten & Goffinet 2009; Govindapyari *et al.* 2010). Research on urban bryophytes in tropical regions, including in Indonesia, is mostly based on inventories and community structures. Studies of urban bryophytes related to air quality have never been conducted in Indonesia. This study aims to compare bryophyte diversity and determine air quality in a residential area and an industrial urban forest area of Jakarta using the IAP.

MATERIALS AND METHODS

Study site

The research was conducted from July to December 2020 in Komplek Taman Bona Indah, a residential area in South Jakarta, and the JIEP urban forest, an industrial area in East Jakarta (Figure 1). Species identification was carried out at the Taxonomy Laboratory of the Biology Department in the Faculty of Mathematics and Natural Sciences, Universitas Indonesia. The voucher specimen was deposited in the Herbarium UI-DEP.

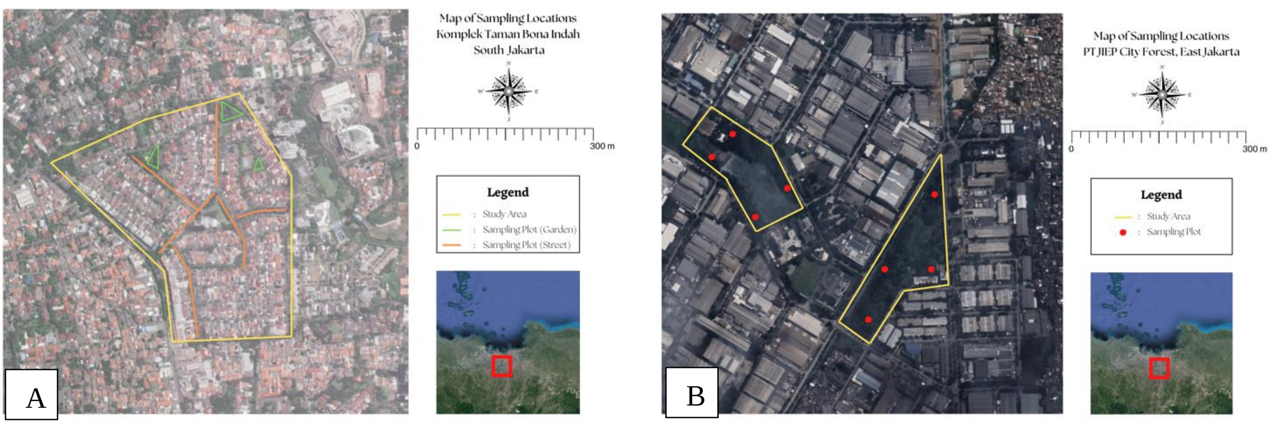

Figure 1 Sampling locations. (A) Taman Bona Indah Residence, (B) JIEP urban forest

Methods

Bryophytes were collected from three substrate types, namely tree trunks, soil and rock or cement in both the Taman Bona Indah residential area and the JIEP urban forest. Samples from the residential area were collected from six sites on a 50 m linear transect at the main roadside and from three sites on a 50 m linear transect in a park. Each transect was divided into 30 × 2 m plots. The bryophytes in the urban forest were collected from eight 25 × 25 m plots. In each plot, five trees with a minimum of 10 cm breast-high diameter were selected. Epiphytic bryophytes were sampled from four cardinal directions with an area of 10 × 10 cm^2 from 0–2 m above ground level. The host tree species and bark type were recorded in a datasheet. In each plot, terrestrial bryophytes were collected from quadrats of 10 × 10 cm^2, and their coverage was estimated using the same quadrats of 10 × 10 cm^2. Voucher bryophyte samples were identified using a stereo and light microscope at the Herbarium UI-DEP, where the voucher specimens were stored.

The bryophyte diversity was analysed using the Shannon–Wiener index and the important value index. The Shannon–Wiener diversity index is calculated using the following formula:

$$H' = -\sum_{i=1}^{S} (pi \ln pi),$$

where:
H' = the Shannon–Wiener diversity index,
S = number of species,
$pi = \frac{Ni}{N}$,
Ni = relative cover species I,
N = relative cover number of S species.

The important value index was measured to analyse species' dominance in each site, as follows (Jiang *et al.* 2020):

$$\text{Important value index} = \frac{\text{Relative cover + relative frequency}}{2}$$

Atmospheric pollution was analysed using IAP according to the following formula (Le Blanc 1971; Jiang *et al.* 2020):

$$IAP = \sum_{i}^{n} \frac{Q\ x\ f}{10}$$

where:
IAP = index atmospheric purity,
Q = ecological index of species (average number of species that coexist with other species),
f = frequency-coverage scale.

RESULTS AND DISCUSSION

Species composition

A total of 24 bryophyte species were recorded in the residential area and the urban forest (three species of liverwort and 21 species of moss). Based on the locations, the species richness in the residential area was higher than in the urban forest. There were three species of liverworts and 15 species of mosses in the residential area, while there were 11 species of mosses and no liverworts in the urban forest (Table 1).

The number of moss species in the urban areas was higher than liverworts (Giordano *et al.* 2004; Szűcs *et al.* 2017; Godovićová *et al.* 2020; Fastanti & Wulansari 2021). Most moss species are known to be drought tolerant, so they are commonly found in open areas (Vitt *et al.* 2014). According to Mukhia *et al.* (2019), a high abundance of epiphytic liverworts is related to low light intensity, ranging from 460–1900 lux. Outside this light intensity range, liverwort abundance is significantly reduced. Consequently, the abundance and species richness of liverwort in urban areas is lower than in natural habitats because of the difference in canopy coverage density and relative humidity.

The families Pottiaceae, Calymperaceae and Bryaceae were found in both sampling sites, with Pottiaceae having the highest number of species (Figure 2). There were eight species of Pottiaceae in the urban forest (*Barbula consanguinea, Barbula pseudo-ehrenbergii*, *Hyophila apiculata, Hyophila beruensis, Hyophila involuta, Hyophila javanica, Trichostomum brachydontium* and *Weissia edentula*). In the residential area, there were five species of Pottiaceae (*Barbula javanica, Hyophila apiculata, Hyophila beruensis, Hyophila involuta* and *Trichosteleum singapurense*) (Table 1). On the other hand, Calymperaceae was represented by more species in the residential area than in the urban forest. Bryaceae was only represented by one species in each of the sampling sites (Figure 2).

Table 1 Bryophyte species composition in the residential area and the urban forest

No.	Species	Family	Location	
			Residential area	Urban forest
	A. Marchantiophyta			
1	*Haplomitrium blumei*	Haplomitriaceae	√	
2	*Lejeunea cocoes*	Lejeuneaceae	√	
3	*Lejeunea eifrigii*	Lejeuneaceae	√	
	B. Bryophyta			
1	*Bryum apiculatum*	Bryaceae	√	
2	*Calymperes crassinerve*	Calymperaceae	√	
3	*Calymperes motleyi*	Calymperaceae	√	√
4	*Calymperes tenerum*	Calymperaceae	√	√
5	*Leucophanes octoblepharioides*	Calymperaceae	√	
6	*Fissidens atroviridis*	Fissidentaceae	√	
7	*Fissidens biformis*	Fissidentaceae	√	
8	*Isopterygium bancanum*	Hypnaceae	√	
9	*Isopterygium minutirameum*	Hypnaceae	√	
10	*Barbula consanguinea*	Pottiaceae		√
11	*Barbula javanica*	Pottiaceae	√	
12	*Barbula pseudo-ehrenbergii*	Pottiaceae		√
13	*Hyophila apiculata*	Pottiaceae	√	√
14	*Hyophila beruensis*	Pottiaceae	√	√
15	*Hyophila involuta*	Pottiaceae	√	√
16	*Hyophila javanica*	Pottiaceae		√
17	*Trichosteleum singapurense*	Sematophyllaceae	√	
18	*Trichostomum brachydontium*	Sematophyllaceae		√
19	*Weissia edentula*	Pottiaceae		√
20	*Taxithelium nepalense*	Sematophyllaceae	√	
21	*Splachnobryum indicum*	Splachnobryaceae		√
	Number of species		**18**	**11**
	Total number of species		**5**	

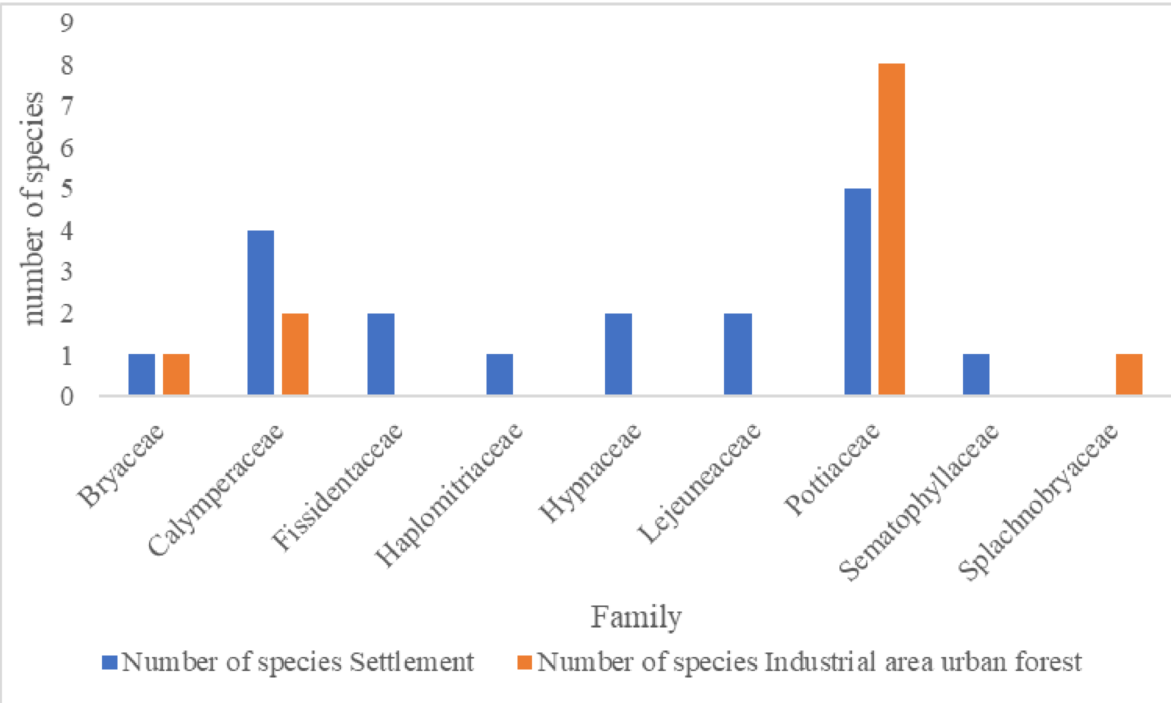

Figure 2 Family composition of bryophytes in the residential area and the urban forest

Pottiaceae is a family of mosses that is present in open and dry environments, particularly in urban areas (Da Costa 2015; Jiang *et al.* 2020). They have a small size, erect stem or acrocarpous with a short turf life-form and dark green gametophore (Figure 3). The members of this family have lanceolate leaves, which become crisped when dry to reduce transpiration due to environmental heat stress. In addition, some species of Pottiaceae have ornamentation on the leaf cell surface, such as papillae. The interstices between papillae are necessary to increase water conduction on the leaf surface (Zander 1993; Kou *et al.* 2014; Glime 2017). Furthermore, they can prevent water loss, making them more successful in a drought.

Calymperaceae is an epiphytic moss that was often found in both sampling locations. Some species of this family have gemmae at the apex of the leaves as asexual reproductive organs, a strategy that helps them survive in unfavorable urban environments. The presence of cancellinae regions (hyaline basal leaf cells) in Calymperaceae is another strategy of this family to retain more water in dry environments (Figure 4) (Glime 2017).

Lejeuneaceae, a cosmopolite family, were the only liverworts in the sampling sites found on the exposed roots of large palm trees 10–20 cm above the ground. This tree root substrate had a low light intensity at around 250 lux, causing a more humid microhabitat. Liverworts generally grow in moist and shady habitats, while epiphytic liverworts grow on large or old trees (Vanderpoorten & Goffinet 2009; Mukhia *et al.* 2019).

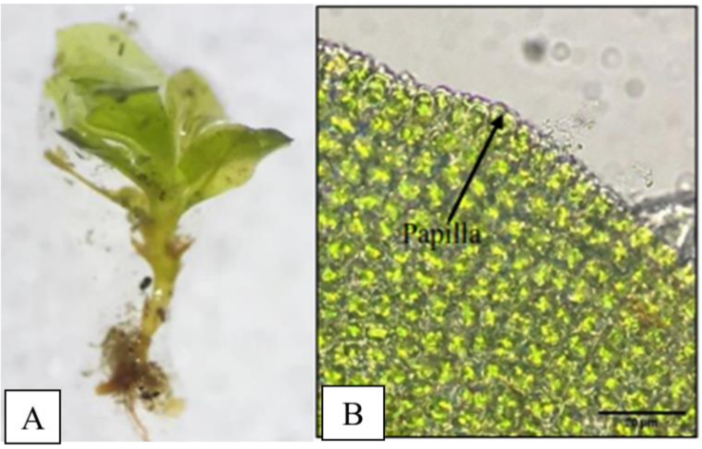

Figure 3 Pottiaceae. (A) Acrocarpous and short turf life-form. (B) Papillae on the leaf surface

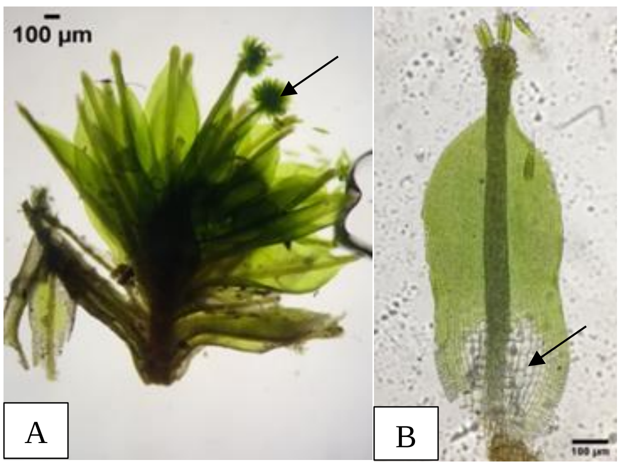

Figure 4 Calymperaceae. A. The gemmae on the leaf apex. B. Cancelinae

The type of substrate with the highest species richness was rock/cement (Figure 5). Cement paths and paving blocks were common kinds of rock and cement substrate in both sampling locations. According to Floyed and Gibson (2012), cement pavement always has crevices and cracked structures that provide a sheltered area for bryophyte colonisation. These surfaces trap soil, water and dust from the atmosphere to support bryophyte growth, provide shelter from mechanical disturbance and retain moisture for a longer period than surrounding surfaces. This substrate was dominated by Pottiaceae, including *Hyophila* and *Barbula*. Those genera are common in disturbed areas, such as urban ecosystems (Zander 1993).

Terricolous bryophytes were found only in the residential area and absent in the urban forest (Figure 5). The soil type in the latter may not have supported bryophyte growth. According to Lubis *et al.* 2013, the JIEP urban forest has a podosol soil type with low moisture and nutrient content. In addition, piles of plastic waste were found in some of the sampling plots. Andayaningsih *et al.* (2013) also reported finding terrestrial pteridophytes in this location, indicating that JIEP's environmental conditions are unsuitable for plants sensitive to dry conditions, such as terrestrial bryophytes and pteridophytes.

The number of epiphytic bryophytes in the residential area was higher than in the urban forest (Figure 5). Air pollution, humidity, temperature and phorophyte variation were limiting factors. The minimum frequency of epiphytic moss in urban areas can be determined from the percentage of host trees covered with epiphytic moss. Twenty-four percent of phorophytes (trees used as hosts of bryophytes) were used as hosts in the residential area. However, only 8% of the urban forest was used by bryophytes as hosts (Figure 6), which shows that industrial areas are more vulnerable to the growth of sensitive bryophyte species than residential areas. Urban forests are surrounded by dense industrial activity and have low vegetation density, which affects microclimate conditions, causing the comfort index in the area to be lower than usual (Syihabuddin *et al.* 2020).

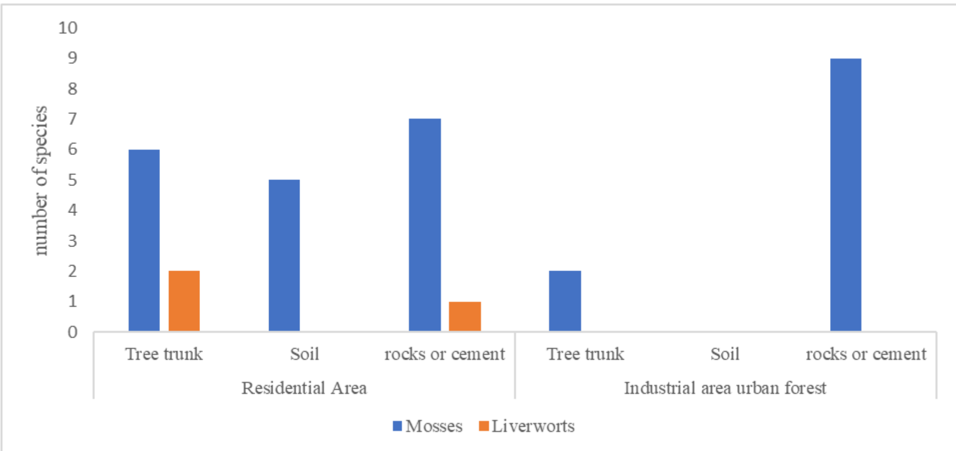

Figure 5 Number of bryophyte species on three substrates in the residential area and the urban forest

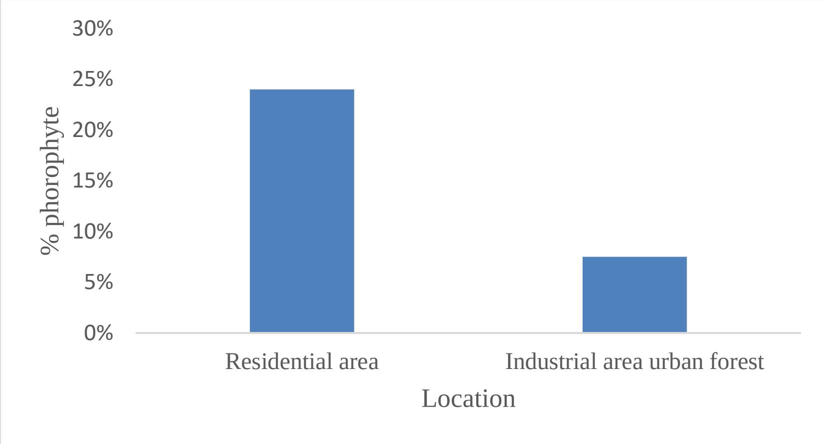

Figure 6 Presentation of phorophytes with epiphyte bryophytes

The characteristics of the host trees also influenced the presence of epiphytic mosses. *Eusideroxylon zwageri* was the only tree species colonized by bryophytes in the urban forest. In the residential area, there were three tree species hosting bryophytes, *Mangifera indica*, *Swietenia mahagoni* and *Roystonia regia*. These trees had rounded canopies and a fissured bark texture, and the pH of the bark varied between 6 and 6.8. The fissured texture had hollow cracks, resulting in a more stable surface for epiphytic bryophytes. It provided a more humid and shaded habitat by retaining water and dust from the atmosphere (Vanderpoorten & Goffinet 2009). Meanwhile, because of the palm trees' smooth bark, there were no epiphytic bryophytes on their bark surface, although they were found on the exposed palm root surfaces near the soil, since these were more humid and shaded than the trunk.

Community structure and index of atmospheric purity

Based on the type of substrate, the bryophyte diversity index in both the residential area and the urban forest ranged from 0 to 2.06. This shows that the bryophyte diversity was very low. No bryophytes were found on the soil substrate in the urban forest, and the lowest diversity index was found in the epiphytic bryophyte community in that location (Table 2). Saxicolous bryophytes on rock/cement substrate in both the residential area and the urban forest had a higher diversity index than those growing on other substrates. This shows that in urban environments, saxicolous bryophytes are more tolerant than the bryophytes on other substrates.

The IAP in the residential area was 4.3, and in the JIEP urban forest, it was 0.3 (Table 2). According to the IAP criteria of Le Blanc and Slover, the air pollution in both locations was found to be highly polluted, in the range of 1–5. Although the level of specific pollutants was unknown, it can be estimated by IAP that the urban forest was more polluted than the residential area in South Jakarta.

Air pollution and microclimate have a negative impact on sensitive species that can reduce IAP values (Jiang *et al.* 2020), which was shown by the lower number of epiphytic bryophytes in the urban forest. Epiphytic bryophytes are not found in urban areas with high pollution levels (Fudali & Żołnierz; 2019: 73; Jiang *et al.* 2020). One of the factors affecting epiphytic bryophyte diversity is traffic density. The absence of liverworts in the urban forest also indicates their sensitivity to industrial environments.

The results showed that the epiphytic mosses with the highest important value index were *Calymperes motley* and *C. tenerum*, while the saxicolous bryophytes with the highest important value index were *Hyophylla javanica* and *H. involuta* in both locations. In addition, the terricolous bryophyte with the highest important value index was *Fissidens biformis* (Table 3).

Table 2 Diversity index and index of atmospheric purity in the residential area and the urban forest

	Location					
	Residential area			Urban forest		
	Tree trunk	Soil	Rock or cement	Tree trunk	Soil	Rock or cement
H'	1.73	1.19	2.06	0.52	–	1.59
IAP	4.3			0.3		

Table 3 The highest important value index of bryophytes

Substrate	Residential area		Urban forest	
	Species	Important value	Species	Important value
Tree	*Calymperes motleyi*	22.02	*Calymperes motleyi*	31.25
	Calymperes tenerum	10.71	*Calymperes tenerum*	26.69
	Calymperes crassinerve	7.74		
Rock or cement substrate	*Hyophila javanica*	37.67	*Hyophila involuta*	15.54
	Hyophila involuta	21.06	*Hyophila javanica*	12.50
	Hyophila apiculata	19.22	*Trichostomum brachydontium*	5.26
Soil	*Fissidens biformis*	35.39		
	Fissidens atroviridis	14.97		
	Isopterygium bancanum	10.10		

Some species of *Calymperes* have also been reported as dominant bryophytes in other urban areas, such as at the Universitas Indonesia campus (Putrika *et al.* 2017) and an urban agroforest in Nigeria (Ezukanma *et al.* 2019). This genus is also commonly found in home yards and oil palm plantations in the Giam Siak Biosphere Reserve (Fastanti *et al.* 2013). From this information, we can assume that some species of *Calymperes* are sun epiphyte bryophytes, since they always grow in open areas and belong to drought-tolerant species.

The highest important value index in both locations was dominated by acrocarpous species, turf and cushion life-forms, which were small, at about 0.4–7 mm. Drought-tolerant moss species are commonly small and have erect stems (Printanakul & Jampetong 2020). In addition, turf and cushion life-forms tend to have dense leaf arrangements, which allows them to optimize water movement and storage as well as prevent excessive transpiration through a dry environment (Spitale *et al.* 2020). Turf and cushion life-forms are commonly found growing terrestrially in open habitats with high light intensity (Kürschner 2004: 105; Glime 2017: 4, 5, 7).

According to the abiotic data, in the residential area and urban forest, the daily temperature and relative humidity ranges were 29–32°C and 50%–61%, respectively. This condition may explain why the diversity of bryophytes in both sampling sites was low. The optimum temperature for bryophyte growth is about 15–25°C (Frahm 2003; He *et al.* 2016). Some bryophyte species in tropical lowland forests cannot survive at 27–30°C. Temperatures above 30°C can inhibit bryophyte photosynthesis (He *et al.* 2016). Furthermore, only specific bryophyte species can survive in urban areas.

CONCLUSION

Bryophyte diversity in both the residential area and the JIEP urban forest was dominated by acrocarpous mosses such as *Calymperes* and *Hyophila*. The residential area had higher bryophyte diversity than the urban forest. The IAP in the urban forest was lower than that in the residential area. However, both locations fell into the category of very heavily polluted areas. Further research is needed to compare the IAP values to the air pollutant quantity to confirm the pollution levels in both study sites.

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