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Diversity and bio-indicators of tropical urban lichens in Jakarta, Indonesia

RIZHAL HENDI RISTANTO[1,♥], MUHAMMAD ALHADY[1], RIFKY ADI SAPUTRA[1], ERICKA DARMAWAN[2]
[1]Department of Biology Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta. Jl. Rawamangun Muka Raya No. 11, Rawamangun, Pulo Gadung, East Jakarta 13220, Jakarta, Indonesia. Tel./fax.: +62-21-4894909, ♥email: rizhalhendi@unj.ac.id
[2]Department of Biology Education, Faculty of Teacher Training and Education, Universitas Tidar. Jl. Kapten Suparman No. 39, Potrobangsan, Magelang 56116, Central Java, Indonesia

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Abstract. *Ristanto RH, Alhady M, Saputra RA, Darmawan E. 2025. Diversity and bio-indicators of tropical urban lichens in Jakarta, Indonesia. Biodiversitas 26: 5505-5514.* Lichens are highly sensitive to air quality changes, making them effective bioindicators for assessing pollution in urban areas. This study analyzed the diversity, dominance, and evenness indices of lichens across urban forests in Jakarta, Indonesia. Sampling was conducted using the cruise and purposive methods, with each administrative city represented by one urban forest park. A total of 18 lichen species were identified, dominated by *Bacidia viridifarinosa* (35,257 individuals). Penjaringan City Forest showed the highest diversity (H': 1.295), dominance (D: 0.667), and evenness (J': 0.723), indicating relatively good air quality. In contrast, Pondok Kelapa (H': 0.142; D: 0.062; J': 0.205) and Srengseng Sawah (H': 0.251; D: 0.071; J': 0.140) were dominated by a single crustose species tolerant to pollution. Although Gelora Bung Karno Forest had more species, one foliose species dominated, suggesting an imbalance. Overall, lichen distribution patterns reflected high air pollution levels in Jakarta, influenced by temperature, pH, and light intensity. These findings confirm that lichen community compositions can reflect air quality gradients and serve as an effective and economic tool to monitor the environment in urban areas. Air pollution can have a serious impact on public health, requiring public education and implementation of curriculum in schools through environmental education.

Keywords: Biodiversity, bioindicator, Jakarta, lichen, urban

INTRODUCTION

Lichens are valuable bio-indicators of air pollution, serving as a permanent monitoring system due to their sensitivity to environmental changes. Their structure includes mycobiont components, which are heterotrophic fungi (Conti and Cecchetti 2001; Loppi 2019; Bhagarathi et al. 2022). Lichens absorb water and nutrients directly from the atmosphere, making them vulnerable to air pollutants like nitrogen compounds, which impact their sustainability. Based on nitrogen tolerance, lichens can be classified into nitrophytes, which thrive in high nitrogen environments, and acidophytes, which are better suited to low nitrogen levels (Sampe et al. 2020; Roziaty et al. 2021).

Urban areas tend to have higher pollution levels than rural ones due to factors such as industrial emissions, traffic congestion, and changes in microclimates (Sobirin and Fatimah 2015; Zettira and Yudhastuti 2022). High concentrations of airborne particles worsen pollution, impacting public health and urban ecosystems (Hermawan 2015; Varela et al. 2018). In Jakarta, Indonesia, air pollution contributes to environmental stress, affecting microorganisms' habitats in urban areas (Putrika et al. 2023). The city, located in a tropical region with intense sunlight and high temperatures, also experiences reduced lichen diversity due to pollution and humidity.

Lichen diversity correlates with air quality: a higher diversity indicates good air, while a lower diversity signals pollution (Hardianto et al. 2015; Mafaza et al. 2019). Due to the lack of cuticle layers and stomata, lichens absorb pollutants directly. In areas with clean air, more pollution-sensitive species are found, whereas only certain species can survive in polluted environments (Panggabean et al. 2020; Sampe et al. 2020). Jakarta has the highest air pollution in Indonesia, leading to a decline in lichen diversity (Syuhada et al. 2023).

Global studies confirm the link between pollution and lichen diversity. In Chile, urban areas showed lower lichen diversity than suburban areas (Varela et al. 2018). Research in Bordj Bou Arréridj found that 60% of epiphytic lichens were crustose and pollution-tolerant, with species like *Xanthoria parietina* and *Physcia aipolia* (Messoud et al. 2019). In Bandung's Bundaran Cibiru Park, Indonesia only *Dirinaria applanata* was found, indicating high pollution (Rohim et al. 2024). A study in Semarang, Indonesia, found *Dirinaria* sp. as a common species across locations (Mafaza et al. 2019). In Colombia, urban areas showed lower diversity than suburban ones, with species like *Candelaria concolor* correlating with NO_2 (Moreno-Palacios et al. 2024). Jakarta's air pollution is considered high, leading to a reduction in moss diversity compared to Depok (Putrika et al. 2023). However, research on lichen diversity in Indonesian urban areas is limited. Given Jakarta's importance, a focused study is needed to explore how lichens can serve as bio-indicators of air quality.

Green open spaces (RTH) in Jakarta serve ecological and social functions. These areas offer spaces for communication, recreation, and education while also absorbing pollution from urban environments. This study aims to evaluate lichen diversity in RTHs across Jakarta and use it to assess the city's air quality.

Previous studies from tropical regions, such as Gebeng, Pahang (Malaysia), identified Graphis scripta as the dominant species, linked to high humidity and CO_2 concentrations due to industrial activities (Abas et al. 2022). In Hanoi, Vietnam, lichen diversity was lower in urban, industrial, and high-traffic areas compared to forests, with poor air quality being the main cause (Khac et al. 2024). Studies in South Asia, such as in Tezpur and Guwahati (India), revealed a connection between human activity, air pollution, and a decline in lichen populations, with high pollution levels threatening their survival (Daimari et al. 2021). Currently, no research has investigated lichen diversity in urban Jakarta, Indonesia. This diversity can be used as a bioindicator of air quality in urban Jakarta, Indonesia. Air quality indicators in Urban Jakarta are an important concern for the sustainability of life of organisms and society. This study aims to analyze the diversity index, dominance index, and evenness index of lichens in urban areas of Jakarta, Indonesia. The research results can indicate which areas have good or poor air quality based on lichen diversity. These findings can be used as a reference for relevant parties to improve air quality in urban Jakarta, Indonesia.

MATERIALS AND METHODS

This research is survey research. The research employed a cruise method with a purposive sampling approach (Widodo et al. 2023). The cruise process was conducted by exploring the research locations at five points or stations that were determined using purposive sampling. Lichen diversity data were collected using a quadrat method. The method was used by choosing sampling points selectively at each encounter with the existing lichen species in a community, with three repetitions.

The observation areas were divided into five city forests in each consisting of five areas in Jakarta, Indonesia (Figure 1). The research location selection took into account Jakarta's urban administrative structure, with each city represented by one city forest park. Furthermore, the forest park location selection also took into account the willingness and cooperation of the Jakarta City Parks and Forestry Service. Sampling locations included North Jakarta (Penjaringan City Forest: -6.132603570504961, 106.7837869036795), Central Jakarta (Gelora Bung Karno (GBK) City Forest: -6.221597321042441, 106.80783194622119), East Jakarta (Pondok Kelapa City Forest: -6.238711957253132, 106.93840380836355), West Jakarta (Kembangan City Forest: -6.17001929337188, 106.75105979486973), and South Jakarta (Srengseng Sawah City Forest: -6.342269877561042, 106.8185040525436). Lichen exploration was conducted on every tree in five urban forest parks, demonstrating the thoroughness of this study. Not all trees have lichen; the area of each city forest varies, namely Penjaringan City Forest, 13.5 ha, with approximately 4,566 shade trees. GBK City Forest 4.5 ha with approximately 60 shade trees. Pondok Kelapa City Forest, 2 ha with approximately 150 shade trees. Kembangan City Forest 2.29 ha with approximately 2,200 shade trees. Srengseng Sawah City Forest 0.57 ha with approximately 500 shade trees.

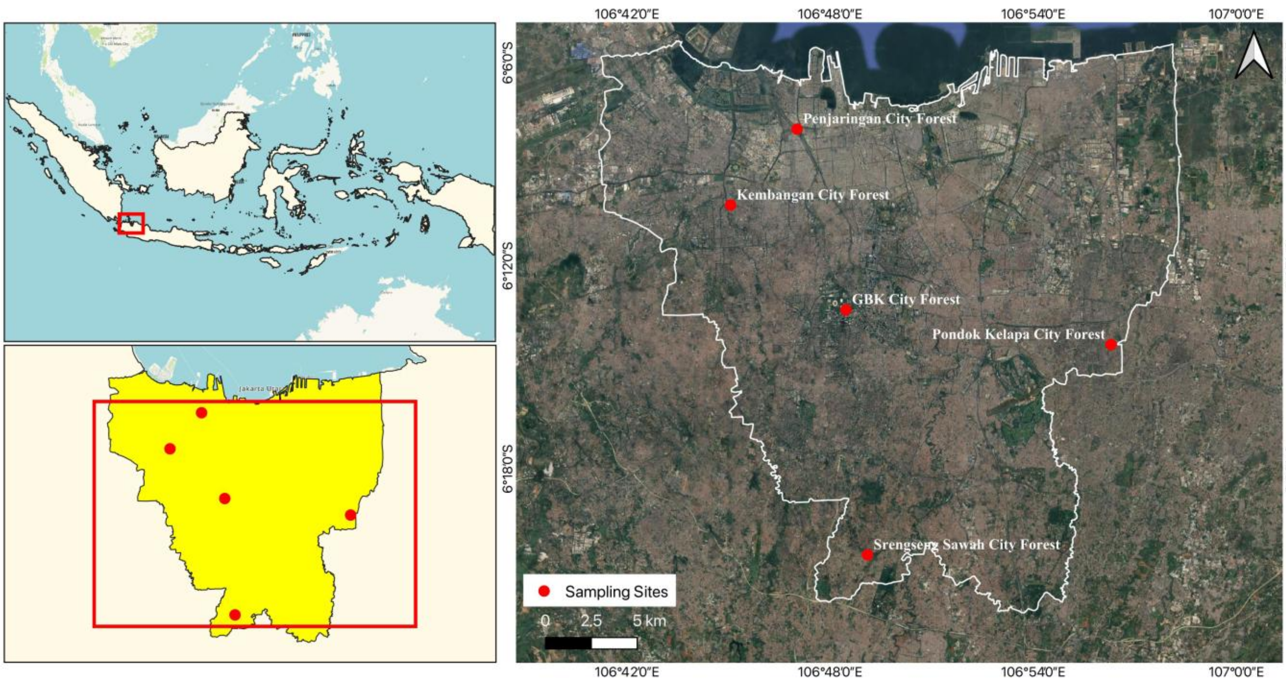

Figure 1. Map of lichen sampling points in Jakarta, Indonesia: Pondok Kelapa City Forest, Kembangan City Forest, Srengseng Sawah City Forest, GBK City Forest, Penjaringan City Forest

The identification process for each lichen found involved collecting the substrate, taking it to the ecology laboratory, and observing it under a magnifying glass. Sampling was carried out on the surface of the tree trunk. Observations began from the base of the trunk to the first branch. If the tree did not have branches, lichen samples were taken up to a height of approximately 2 meters (Leith et al. 2005). The lichen surface area was measured using a 20x20 cm frame, which had been marked with colored markers (Nursal et al. 2005). Lichen identification was based on documentary photographs and conducted at the Ecology Laboratory, Universitas Negeri Jakarta. Data were analyzed by the Lichen Diversity Book (Muvidha 2020). The data collection was carried out from March to June 2025 during high rainfall. Sampling observations at each location were carried out three times over three weeks. The selection of the research locations considered utilization zones that accessed the locations, regulations, and pre-observation results of lichen diversity in tree substrates. Figure 1 depicts the location map. The observation results were analyzed with diversity level (Shannon-Weiner index), dominance level (Simpson's Diversity Index), and evenness level (Pielou's Evenness Index). In addition, the physical factors considered in this study include temperature, pH, light intensity, and Air Quality Index (AQI) of Jakarta. AQI in this study refers to reports from (Turyanti et al., 2024). These approaches aimed to ensure that the Lichen species found in Jakarta's city forests were represented in the sampling process.

RESULTS AND DISCUSSION

The research findings indicate 18 lichen species from 7 orders. Their species distribution map is illustrated in Figure 2. The number of lichen species observed in this research exceeded those reported by Sampe et al. (2020) in Tebet Eco Park City Forest Park, South Jakarta, and in GBK City Forest, Central Jakarta, which documented 6 lichen species. Variation in the number of lichen species recorded in various research locations was due to differences in the research duration, sampling intensity, exploration areas in the city forests, and diverse environmental conditions based on habitats preferred by lichen species. Table 1 provides five city forest parks that become the research objects have environmental factors that support the growth of lichen, including air humidity ranging between 69.5% and 88%, air temperature between 29°C and 33°C, and monthly rainfall in April and May in Jakarta areas that was relatively moderate, around 100-200 mm. As a poikilohydric organism, water content in lichens follows air humidity in their surroundings. This unique ability makes them very drought-tolerant; however, on the other hand, they are very vulnerable since they absorb water and nutrients directly from the atmosphere. This vulnerability underscores the need for environmental protection, as lichens can absorb dissolved pollutants in the air that could damage their internal tissues (Roziaty 2016; Stanton et al. 2023). Although their growth is increasing during the rainy season, research indicates that the total amount of rainfall is not the main determining factor. On the contrary, the most important factor for lichens is how often they get water, since it determines their growth rate (Armstrong 2015; Phinney et al. 2021). Air pollution in five city forests observed from April to May varied between 60 and 111 AQI. As an environmental factor, pollution level indicates a strong correlation to lichen diversity, where areas with higher pollution tend to have lower lichen communities (Chaparro 2021; Belguidoum et al. 2022; Delves et al. 2023).

The Lichen order mostly found is Graphidales and Lecanorales, consisting of 7 species. The most specific character to identify the order Graphidales is their unique reproduction organ called lirellae, which are ascomata structures that are elongated, branched, or star-shaped. In addition to this main marker, this order is also known as a very dominant lichen group with broad distribution from low to highland. They live inclusively on barks, attaching themselves tightly to rough and cracked surfaces, which aids in the absorption of nutrients from rainwater. One of its genera, *Graphis*, indicates how easy this order is to adapt since it requires less water to grow (Kusmoro et al. 2018; Fahmi et al. 2024). The order Lecanorales is commonly found in tropical to subtropical climates, even in the Arctic and Antarctic. These species can survive in a wide range of climates and are among the most diverse lichens (Lee and Hur 2022; Park et al. 2023). Table 2 shows 18 lichen species recorded in several research areas and growing on tree bark substrates.

Tree bark, with its porous texture and protective structure, acts as a shield for lichens; it provides an ideal environment for lichen growth due to several advantages. Its porous texture can retain moisture; at the same time, its structure protects from excessive exposure to sunlight and drying wind. The combination of these factors creates a stable and humid microenvironment essential for lichens to attach and grow. This explains why this substrate is abundant compared to other substrates (Almer and Werth 2024). Some of the species found in this study are documented and presented in Figure 2.

Discussion

Lichen thallus

Lichen shows various shapes of thallus, including foliose, crustose, fruticose, squamulose, and filamentous. In the research in Jakarta areas, 18 species were classified as crustose lichens, including *Graphis scripta, D. applanata, Candelariella reflexa, Bacidia rubella, Arthonia patellulata, Pertusaria* sp., *Bacidia viridifarinosa, Phaeographis neotricosa, Fissurina insidiosa, Graphis handelii, Pyrenula nitida, Graphis crebra, Cryptothecia striata, Graphis plumierae, Bacidia insularis, Flavoparmelia caperata, Amandinea caniops*, and *Graphis librata*. Two species were categorized as foliose lichens, namely *D. applanata* and *F. caperata*.

Figure 2. A. *Graphis scripta*, B. *Dirinaria applanata*, C. *Candelariella reflexa*, D. *Bacidia rubella*, E. *Arthonia patellulata*, F. *Pertusaria* sp., G. *Bacidia viridifarinosa*, H. *Phaeographis neotricosa*, I. *Fissurina insidiosa*, J. *Graphis handelii*, K. *Pyrenula nitida*, L. *Graphis crebra*, M. *Cryptothecia striata*, N. *Graphis plumierae*, O. *Bacidia insularis*, P. *Flavoparmelia caperata*, Q. *Amandinea caniops*, R. *Graphis librata*

Crustose lichens indicate greater resistance to temperature rise compared to foliosa, fruticose, and filamentosa species. This resistance is related to a lower surface-to-volume ratio, meaning that less surface area is exposed to the atmosphere, resulting in a higher tolerance to drought. Therefore, water loss in crustose lichen is limited to the exposed upper surface. This trend is also seen from the tendency of the percentage of crustose lichen to increase along with the increase in average annual temperature (Nascimbene and Marini 2015; Tumur et al. 2025).

Environmental conditions

The temperature in all research locations ranged between 29°C and 33°C (Table 1). This range reflects a consistent warm urban tropical climate. The Gelora Bung Karno (GBK) City Forest was consistently at the highest temperature, ranging from 32°C to 33°C. The highest temperature was affected by low vegetation density, the far distance between trees, and the building infrastructure in the forest area that is surrounded by glass buildings that reflect sunlight. Whereas, locations such as Srengseng Sawah and Kembangan City Forests indicate a slightly lower temperature, around 29°C to 32°C. It is indicated by denser tree vegetation compared to GBK City Forest, and there are no high-rise glass buildings. This variation, although only several degrees, indicates microclimate differences between locations. Temperatures above 40°C are a critical limit for lichen survival since they could damage its chlorophyll. Consequently, it will inhibit the photosynthesis process; therefore, optimum growth can only be achieved in temperatures below the limit (Anwari 2021; Ramadhanti et al. 2021).

The pH acidity level, ranging from a slightly acidic 5.1 to a nearly neutral 6.4, is a key determinant of lichen diversity (Table 1). The Kembangan City Forest, with its more acidic soil pH compared to other city forests, hosts the largest lichen diversity, comprising 4 species. This soil acidity is instrumental in influencing lichen diversity, as it supports the growth and survival of specific lichen species. The types of crustacean thallus that indicate a higher preference or tolerance to acidic environmental conditions, since they are often found on substrates with low pH. Additionally, low pH environments play a crucial role in creating more optimal conditions for development and biological activities, for example, increasing nutrient availability or reducing competition with other organisms (Atni et al. 2024). The pH acidity of substrates influences the distribution of thallus types, where crustose and foliose show wide adaptability in various pH conditions; on the contrary, filamentous thallus is rarely found. Of all types, crustose thallus is considered the most efficient due to its strategy in managing water with minimal water requirement and the ability to retain moisture through its attachment to the substrates (Madjeni et al. 2020; Kamaluddin et al. 2022).

Species found in a very high light intensity include *P. neotricosa* and *B. rubella*. In comparison, species that grow well in low light intensity include *B. viridifarinosa* in Pondok Kelapa and *C. striata* in Kembangan. Light intensity significantly influences the lichen photosynthesis process, in which they are known for being capable of performing photosynthesis effectively in low light intensity values, around 1035 lux (Widodo et al. 2023). This is in line with findings in specific lichen species, such as 'Cet' (lichens that are not exposed to direct sunlight), which indicates a very high efficiency in photosynthesis in low light conditions. The efficiency is proven by the 1-qP values (pressure in PSII) approaching zero at low light, indicating its electron transport is running smoothly. On the contrary, at high light intensity, the efficiency of 'Cet' actually decreases, and the pressure on the PSII reaction center sharply increases, indicating that lichens cannot grow maximally with high light intensity (Osyczka and Myśliwa-Kurdziel 2023).

Table 1. Distribution of lichen in Jakarta Province, Indonesia: Pondok Kelapa City Forest, Kembangan City Forest, Srengseng Sawah City Forest, GBK City Forest, Penjaringan City Forest

Location	Species	Figure	Order	Thallus	Temperature	pH	Light Intensity	Total of association
Penjaringan, North Jakarta (NJ)	*Graphis scripta*	2.A	Graphidales	Crustose	31.6°C	6.2	7,283.3 Lux	87
	Dirinaria applanata	2.B	Caliciales	Foliose	30.3°C	5.8	1,732 Lux	907
	Candelariella reflexa	2.C	Candelariales	Crustose	30°C	6.2	2,634 Lux	1,587
	Bacidia rubella	2.D	Lecanorales	Crustose	30.5°C	6.2	9,351 Lux	41
	Arthonia patellulata	2.E	Arthoniales	Crustose	29°C	6.4	1,384.6 Lux	550
	Pertusaria sp.	2.F	Pertusariales	Crustose	31°C	5.2	5,446 Lux	151
Total								3,323
Srengseng Sawah, South Jakarta (SJ)	*Dirinaria applanata*	2.B	Caliciales	Foliose	30°C	6.2	4,035.6 Lux	1,096
	Bacidia viridifarinosa	2.G	Lecanorales	Crustose	32°C	6.2	4,023 Lux	32,983
	Phaeographis neotricosa	2.H	Graphidales	Crustose	29.6°C	5.5	17,660 Lux	49
	Fissurina insidiosa	2.I	Graphidales	Crustose	29°C	5.1	4,056.3 Lux	1
	Graphis handelii	2.J	Graphidales	Crustose	29°C	6.3	3,136 Lux	83
	Pyrenula nitida	2.K	Pyrenulales	Crustose	29°C	5.3	8,896.3 Lux	27
Total								34,239
Kembangan, West Jakarta (WJ)	*Dirinaria applanata*	2.B	Caliciales	Foliose	30°C	5.1	2,363.3 Lux	568
	Graphis crebra	2.L	Graphidales	Crustose	31°C	5.6	1,640 Lux	58
	Bacidia viridifarinosa	2.D	Lecanorales	Crustose	30°C	5.2	871.3 Lux	1,005
	Cryptothecia striata	2.M	Arthoniales	Crustose	30°C	6.1	845 Lux	82
Total								1,713
Pondok Kelapa, East Jakarta (EJ)	*Bacidia viridifarinosa*	2.D	Lecanorales	Crustose	31.6°C	5.8	251.6 Lux	1,264
	Candelariella reflexa	2.C	Candelariales	Crustose	30.6°C	5.8	1,184 Lux	42
Total								1,306
Gelora Bung Karno, Central Jakarta (CJ)	*Graphis plumierae*	2.N	Graphidales	Crustose	33°C	5.2	8,996.6 Lux	5
	Bacidia viridifarinosa	2.D	Lecanorales	Crustose	32.3°C	5.5	6,446.6 Lux	5
	Dirinaria applanata	2.B	Caliciales	Foliose	32.6°C	5.2	7,783.3 Lux	385
	Bacidia insularis	2.O	Lecanorales	Crustose	32.6°C	5.2	8,026.6 Lux	17
	Flavoparmelia caperata	2.P	Lecanorales	Foliose	32°C	6.1	4,913.3 Lux	3
	Amandinea caniops	2.Q	Caliciales	Crustose	32°C	6.1	7,153.3 Lux	1
	Graphis librata	2.R	Graphidales	Crustose	33°C	5.2	4,273.3 Lux	5
Total								421
Total of association								41002

Table 2. Species, thallus, substrat, present-absent matrix of all fern species in 18 urban lichens in Jakarta, Indonesia

Species	Thallus	Substrat	Penjaringan	Srengseng Sawah	Kembangan	Pondok Kelapa	Gelora Bung Karno	Sum
Graphis scripta	Crustose	Tree	1	0	0	0	0	1
Dirinaria applanata	Foliose	Tree	1	1	1	0	1	4
Candelariella reflexa	Crustose	Tree	1	0	0	1	0	2
Bacidia rubella	Crustose	Tree	1	0	0	0	0	1
Arthonia patellulata	Crustose	Tree	1	0	0	0	0	1
Pertusaria sp.	Crustose	Tree	1	0	0	0	0	1
Bacidia viridifarinosa	Crustose	Tree	0	1	1	1	1	4
Phaeographis neotricosa	Crustose	Tree	0	1	0	0	0	1
Fissurina insidiosa	Crustose	Tree	0	1	0	0	0	1
Graphis handelii	Crustose	Tree	0	1	0	0	0	1
Pyrenula nitida	Crustose	Tree	0	1	0	0	0	1
Graphis crebra	Crustose	Tree	0	0	1	0	0	1
Cryptothecia striata	Crustose	Tree	0	0	1	0	0	1
Graphis plumierae	Crustose	Tree	0	0	0	0	1	1
Bacidia insularis	Crustose	Tree	0	0	0	0	1	1
Flavoparmelia caperata	Foliose	Tree	0	0	0	0	1	1
Amandinea caniops	Crustose	Tree	0	0	0	0	1	1
Graphis librata	Crustose	Tree	0	0	0	0	1	1
Total			6	6	4	2	7	

Quantitatively, pH, temperature, and light intensity form a microclimate that determines lichen survival. Temperature regulates the rate of metabolism and transpiration of the thallus, so that an increase of only a few degrees can shift the species composition toward more heat-tolerant groups. pH influences the availability of nutrient ions and the toxicity of metals in the substrate. Light intensity plays a role in regulating photosynthetic productivity. These three variables simultaneously can predict zones with lichen diversity and design urban planning interventions, such as planting vegetation or regulating canopy cover, to create optimal microclimate conditions for lichen sustainability as bioindicators (Nascimbene and Marini 2015; Sett and Kundu 2016; Gasulla et al. 2021).

A study by the indicates that air pollution in Jakarta is moderate (Figure 3). These results are relevant to the findings of this study, which found that lichen species diversity in Jakarta is low (Table 2). The most common lichen species found in Jakarta are crustose (Tables 1 and 2). *Bacidia viridifarinosa* was found in almost all research locations except Penjaringan, North Jakarta. This species, with its crustose thallus, has a high tolerance to pollutants. The thallus of crustose lichens is more tolerant of pollution (Kusmoro et al. 2019). The diversity index, thallus species, and air pollution data in Jakarta (Figure 3) reflect the poor air quality in urban Jakarta.

Bioindicator

The distribution and diversity of lichens in the five main city forest areas in Jakarta provide a precise reflection of local air quality conditions. The role of lichen as a bio-indicator, due to its high sensitivity to atmospheric pollutants, particularly sulfur dioxide (SO_2) and nitrogen oxides (NOx), is a key aspect. The study reveals a clear correlation: a cleaner air environment fosters the growth of diverse lichen communities, including the presence of foliose morphotypes that are more sensitive. However, in zones with high pollutant concentrations, the impact is significant: community simplification occurs, with only crustose morphotype lichens able to survive due to their high tolerance, while other, more vulnerable species are negatively selected from the habitats (Roziaty 2016; Kumari et al. 2024).

Humidity and temperature play important roles in the physiological activity of lichens due to their poikilohydric nature. These factors are not always the primary cause of the decline in lichen diversity. These climatic factors function more as physiological constraints that determine the photosynthesis process in lichens. Air pollution can be a dominant factor causing a reduction in lichen diversity (Gauslaa 2014; Chowaniec et al. 2023).

Penjaringan City Forest occurs as a location with the best ecological condition, indicating the relatively best air quality among the studied areas. Table 3 shows the values of Shannon Diversity Index (H') of 1.295 and Evenness Index (J') of 0.723. These values suggest that the community structure in this location is rich in species variation and is also distributed evenly. Empirical evidence that supports this finding is the significant presence of foliose type lichens, *D. applanata*, that grows well side-by-side with crustose species. These two species are strong bioindicators of a healthy environment. Kembangan City Forest is in the second position with a good diversity and evenness level. The presence of foliose lichens in this area indicates air quality that is relatively conducive to supporting the survival of species that are more sensitive to pollutants (Sett and Kundu 2016; Rimanda 2025).

The environmental conditions in the Pondok Kelapa and Srengseng Sawah City Forests indicate significant ecological differences as reflected by very low biodiversity and bio-evenness values. An extreme domination by a very-tolerant crustose lichen, namely *B. viridifarinosa*, of more than 96% in both locations is a strong indicator of poor air quality. This condition, coupled with the almost complete absence of the more sensitive foliose lichen types, strengthens the assumption that high air pollution levels have eliminated other species that cannot survive. This phenomenon is in line with findings from Gupta et al. (2025) stating that related species such as *Bacidia convexula* and *B. submedialis* are reliable indicators to monitor air quality in urban areas. These species have a high ability to adapt to urban air pollution levels that are higher than rural areas; therefore, their dominant existence indicates a polluted environment.

A more complex case was identified in Gelora Bung Karno (GBK) City Forest. Although it hosts the most species, with seven species, its diversity and evenness are low. This is mainly due to a strong domination of one foliose species, *D. applanata*, whereas the presence of other species is quite minimal. The city forest shows humidity and receives maintenance from the park officers. This causes lichen habitats in the area to receive sufficient water to grow well. This phenomenon suggests that although GBK's air quality is fairly good to support a relatively sensitive species, its imbalanced community structure leads to the conclusion that air quality in GBK is indicated as poor. This is due to its location, which is surrounded by sources of dense traffic emissions. Environmental pressure no longer causes species loss but triggers a shift in species composition (Koch et al. 2019). An area with high pollution is typically dominated by a species such as *D. applanata*. This aligns with conditions in GBK, where seven species can survive, but their community structure is disrupted by the dominance of one species. The results of the observations showed that in Jakarta the dominant species were *B. viridifarinosa* and *D. applanata* with a total of approximately 35,252 and 2,956 species.

Table 3. Parameters of Shannon Weiner Diversity Index, Simpson's Diversity Index, Pielou's Evenness Index in each urban forest, Jakarta, Indonesia

Parameter	Penjaringan (North Jakarta)	Srengseng Sawah (South Jakarta)	Kembangan (West Jakarta)	Pondok Kelapa (East Jakarta)	Gelora Bung Karno (Central Jakarta)
Shannon Weiner Diversity Index	1.295	0.251	0.939	0.142	0.419
Simpson's Diversity Index	0.667	0.071	0.542	0.062	0.162
Pielou's Evenness Index	0.723	0.140	0.677	0.205	0.215

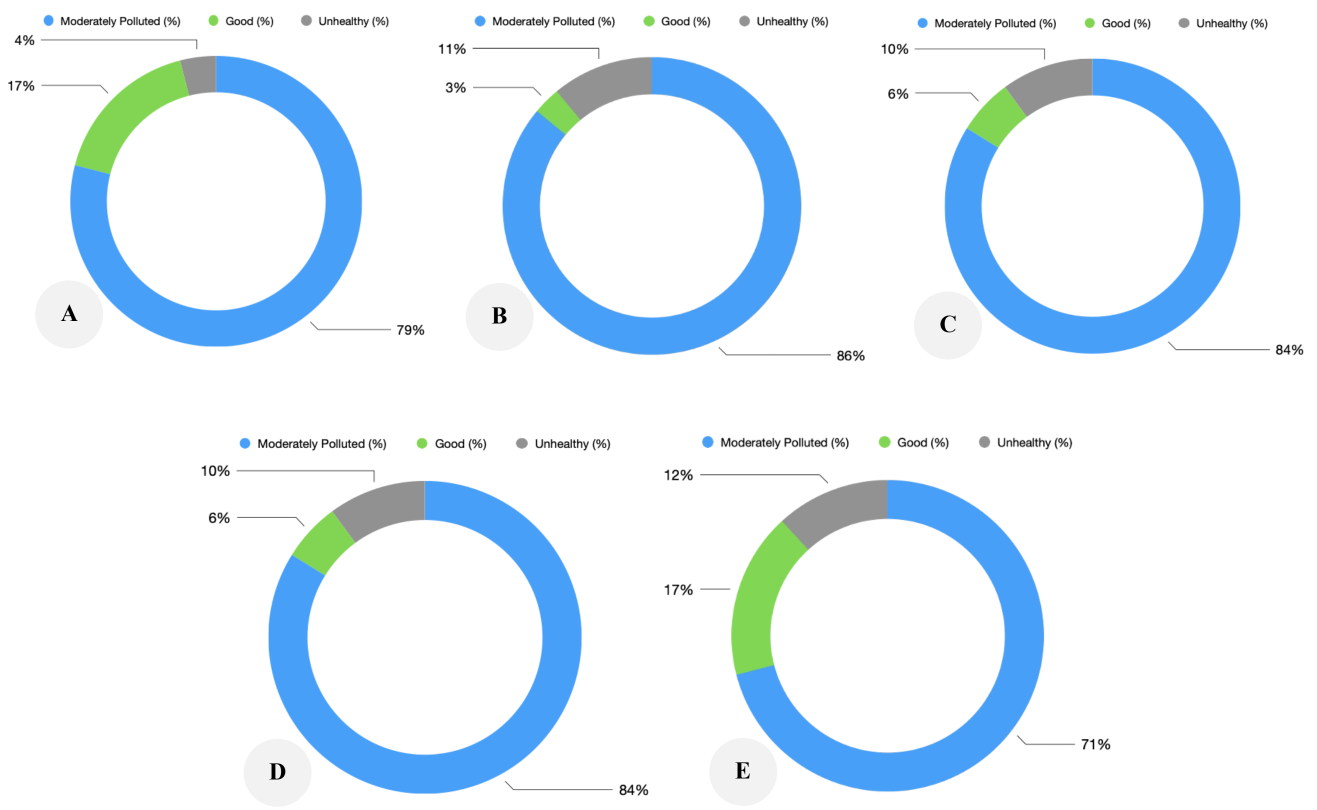

Figure 3. Air pollution in the urban forest, Jakarta, Indonesia. A. Central Jakarta, B. North Jakarta, C. South Jakarta, D. East Jakarta, E. West Jakarta (Turyanti et al. 2024).

The use of lichen as an air quality bioindicator for SO_2 and other atmospheric pollutants. Lichens' high capacity to adsorb heavy metals and nitrogen makes them good indicators of specific pollutants, especially in areas with metal deposition. A multi-bioindicator approach, including lichens, mosses, and faunal indicators, is the most comprehensive for assessing urban air quality. This approach reduces the bias of a single bioindicator and allows for a more in-depth analysis of pollutant types and their impacts on ecosystems (Zvereva and Kozlov 2011; Pescott et al. 2015; Gutiérrez-Larruga et al. 2020). Long-term air pollution in Jakarta has caused changes in the structure of lichen communities. This is indicated by a decrease in diversity in several urban forests (Table 1). Locations with better air quality, such as Penjaringan, have high diversity and uniformity indices. Areas with higher pollution, such as Pondok Kelapa and Srengseng Sawah, are dominated by only one pollution-tolerant species. This indicates that pollution suppresses sensitive species and may lead to the future emergence of pollution-tolerant species in Jakarta. Consequently, the ecological function of lichens as microhabitats is reduced, potentially disrupting the quality of the city's ecosystem and public health (Llewellyn et al. 2020; Abdillah 2024).

A clear air quality gradient mapping in all urban landscapes in Jakarta reveals that the air quality in the city is quite poor and poses a significant risk to human health, particularly in the long term. Without intervention from the local government to control traffic density, increase green spaces, and address industrial pollution, air conditions in Jakarta are predicted to experience a continuous decline every year (Salsabila 2020; Dumiadi et al. 2024). This underscores the urgency for the government to formulate holistic and sustainable policies, so that in the future the diversity of lichens in Jakarta can be more diverse, indicating good air quality, so that it can become a family-friendly urban area (Chen et al. 2023; Bainomugisha et al. 2024).

This study was limited by the absence of chemical or molecular analyses to validate pollution tolerance mechanisms among recorded lichen species, which could have strengthened causal interpretation. The research also focused only on epiphytic lichens on tree bark, excluding those growing on other substrates such as rocks or artificial surfaces, potentially restricting the overall representation of lichen diversity. Seasonal variation was not included, as sampling occurred within a single period, which may influence species composition and abundance due to temporal changes in rainfall and humidity. Future studies should integrate elemental or molecular identification (e.g. XRF, ICP-MS, or DNA barcoding) to confirm species-level accuracy and pollutant bioaccumulation patterns. Expanding sampling sites, incorporating additional environmental parameters (NO_2, SO_2, and $PM_{2.5}$ concentrations), and conducting year-round monitoring are recommended to provide a more comprehensive understanding of how lichen diversity reflects urban ecological health.

In conclusion, lichen communities in five city forests in Jakarta accurately reflect air quality gradients. The forest in Penjaringan City has the highest levels of evenness (J': 0.723), dominance (D: 0.667), and variety (H': 1.295), implying that the quality of the air is generally favorable. This is indicated by the presence of lichen species such as *B. viridifarinosa*, which is known for its sensitivity to air pollution. Conversely, a single crustose species that can withstand pollution predominates in Pondok Kelapa (H': 0.142, D: 0.062, J': 0.205) and Srengseng Sawah City Forests (H': 0.251, D: 0.071, J': 0.140). The GBK City Forest has the greatest number of species; however, it shows an imbalanced community structure due to a strong dominance by one species, which also indicates poor air quality. The findings demonstrate that lichen-based monitoring provides a simple and cost-effective approach for assessing urban air quality in tropical regions. Incorporating lichen observation into school curricula and community-based environmental programs could strengthen public awareness and long-term conservation engagement. These results provide essential baseline data for integrating lichen biomonitoring into Jakarta's urban planning and ecological management policies. To identify lichens as bioindicators in urban Jakarta, Indonesia, while accounting for pollution levels, future studies should employ stratified random sampling across pollution gradients and replicate per stratum. Molecular identification will make the procedure of identifying lichen species more thorough. Lichen variety in urban Jakarta during the dry season must be recognized in order to add to the study's findings.

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