diversity

MDPI

Article

A Preliminary Assessment of Lichens in Different Landscapes of Hanoi, Vietnam

Hoang Ngoc Khac [1], Le Dac Truong [1], Nguyen Thi Hong Hanh [1], Nguyen Thi Hong Lien [2], Nguyen Quoc Binh [3], Vo Thi Phi Giao [4], Pham Hong Tinh [1] and Bui Thi Thu [1,*]

[1] Faculty of Environment, Hanoi University of Natural Resources and Environment, Hanoi 100000, Vietnam; hnkhac@hunre.edu.vn (H.N.K.); ldtruong.mt@hunre.edu.vn (L.D.T.); nthhanh.mt@hunre.edu.vn (N.T.H.H.); phtinh@hunre.edu.vn (P.H.T.)
[2] Faculty of Biology, Hanoi National University of Education, Hanoi 100000, Vietnam; liennth@hnue.edu.vn
[3] Vietnam National Museum of Nature, Hanoi 100000, Vietnam; binhzing@gmail.com
[4] Faculty of Biology-Biotechnology, University of Science, Vietnam National University—Ho Chi Minh City, Ho Chi Minh City 700000, Vietnam; vtpgiao@hcmus.edu.vn
* Correspondence: btthu.mt@hunre.edu.vn

Abstract: Hanoi is the capital of Vietnam, with a total area of 3359.82 km^2 and a population of about 8.4 million people. This is one of the most developed cities in Vietnam, with an urbanization rate of 60%. In this study, we investigated how developed and urbanized areas may influence lichen diversity in Hanoi. The lichen community from Hanoi was studied using three tree stands from each of five landscapes: natural vegetation, industrial parks, urban and rural areas, and roadsides. Lichen species and their cover abundance were recorded on tree trunks at heights from 30 to 150 cm above ground in ten host trees that were randomly selected for each replication. Sixty-seven lichen species, from sixteen families and eight orders, were recorded. Results showed urbanization and the development of industrial parks and transportation altered species composition, evidenced by a reduced number of lichen species. Natural forests sustained the highest lichen diversity measured. These results suggest that a greater diversity of lichen can be preserved in natural forests, if that natural vegetation is effectively managed and conserved.

Keywords: lichens; natural forests; urban area; Hanoi; Vietnam

check for updates

Academic Editor: Michael Wink

Received: 11 November 2024
Revised: 8 December 2024
Accepted: 25 December 2024
Published: 30 December 2024

Citation: Khac, H.N.; Truong, L.D.; Hanh, N.T.H.; Lien, N.T.H.; Binh, N.Q.; Giao, V.T.P.; Tinh, P.H.; Thu, B.T. A Preliminary Assessment of Lichens in Different Landscapes of Hanoi, Vietnam. *Diversity* **2025**, *17*, 27. https://doi.org/10.3390/d17010027

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Lichens are complex organisms with various components, mainly symbiotic fungi and algae. Lichen algae are generally single-celled green algae, cyanobacteria, or both [1]. In this symbiotic relationship, fungi absorb water and inorganic salts from the surrounding air, and provide shelter to algae which can photosynthesize and produce organic materials for lichen growth. Larry McKane and Judy Kandel (1996) stated that this characteristic can exist anywhere in the world, from a familiar environment to harsh living environments. Lichens absorb water, minerals, and many other compounds directly from the surrounding air; however, factors including temperature, humidity, light, and NO_x and SO_x gas can affect their physiology, biochemistry, growth, and diversity [2].

According to their external thallus morphology, lichens are classified into three types: (1) crustose lichens are firmly bound to the substrate without leaving a free margin, and are difficult to collect; (2) foliose lichens are loosely bound to the substratum, flattened, and leaf-like; and (3) fruticose lichens are attached to the substratum at one point only, with a mostly highly branched or shrubby appearance [3]. Lichens have two main growth phases:

the sexual phase and the asexual phase. During sexual reproduction, the lichen fungus produces fruit bodies and spores. These spores form new hyphae and combine with the appropriate algae to form new lichen individuals. Lichen algae usually reproduce by cell division, and most lichens reproduce asexually. During the asexual phase of lichens, special propagations found only in lichens help to facilitate the vegetative dispersion. These small outgrowths (known as isidia and soralia) on the upper surface of the thallus are easily broken, and after dispersal, they are able to develop hyphae [4]. The growth rate of lichens depends on many factors in their living environment, including the soil structure, weather, humidity, nutrient absorption, and metabolism. These factors affect the ability of lichens to absorb and retain water and nutrients. Lichens grow very slowly: scaly lichens grow from 0.1 to 10 mm per year, and leaf lichens grow from 2 to 4 cm per year [5].

The impact of environmental factors such as temperature, light, humidity, and gas (NO_2, SO_2, CO_2) emitted into the environment by human activities; alterations in morphology, biology, etc.; loss of certain species (natural selection mechanism); or the existence of certain species (adaptation mechanism), clearly shows the relationship between lichens and environmental quality [6–8]. Lichens are sensitive to toxic gases, especially SO_2, which causes the conversion mutation of chlorophyll-a to phaeophytin; this weakens the photosynthetic components and affects lichen diversity. Therefore, the cover and species composition of lichens are greatly affected in industrial areas and traffic routes where concentrations of various air pollution gasses are high. In particular, lichen species characterized by fruticose and foliose thali have disappeared [7].

Since the first report in 1866 on the effect of air pollution on lichen deterioration in urban areas, numerous lichen species have been identified as indicators of air pollution [7]. The aim of this study was to highlight the most important lines in this field and to evaluate this lichen-based method and its advantages and disadvantages compared to traditional methods [7]. Richardson (1992) [9] and Gries (1996) [10] compared two different methods for using lichen as biological indicators of air pollution and biological surveillance: (1) mapping all species present in a specific area; (2) sampling lichen and determining pollutants in tissues; measuring the morphological change of lichen colonies; and assessing physiological parameters or evaluating pollutant bioaccumulation. In 2004, Pinho et al. suggested that lichen mapping should be the first step in assessing air quality [11]. In a 2008 report, Jovan assessed lichen biodiversity indicators, air quality, and climate change on the basis of monitoring results in Washington, Oregon, and California [12]. In 2010, Susan Will-Wolf analyzed lichen bioindicator data from the Forest Inventory and Analysis Program and reported on forest health, air quality, and climate. The Lichen Diversity Index was determined in all the survey regions. The air quality was determined by modeling the composition of the lichen diversity indices [13] based on the composition of lichen species in the survey plots. Sally et al. (2010) studied the association between the relationship of the lichen community and the concentration of NO_2 and NH_3 in north-east London [14].

Since the late 19th century, in Vietnam, Müller (1891) [15], Hue (1901) [16], Schmid (1974) [17], Tixier (1966) [18], Pham Hoang Ho (1970) [19], Vo Thi Phi Giao (2009) [20], Nguyen Thi Thuy et al. (2010, 2011) [21–23], Jayalal et al. (2013) [24], Joshi et al. (2013) [25–27], and Nguyen Thi My Dung (2013) [28] have conducted lichen-related studies. However, these studies focused mainly on the species composition and diversity of lichens in natural ecosystems in the central highlands and southern Vietnam. Recently, Thai Khac Dinh et al. (2008) [29] evaluated the absorption of metals (Br, Na, Ka, Zn) in lichens collected in parks in Ho Chi Minh City. Nguyen Thanh Luc (2020) [30] studied the correlation between lichen coverage and environmental factors such as CO, NO_x, total suspended particulate matter (TSP), and PM_{10}. Therefore, the data on lichens in northern Vietnam, especially in northern cities like Hanoi, are still very limited.

This paper presents preliminary research results on the diversity of lichens in different habitats (industrial, agricultural, traffic routes, etc.) in Hanoi, Vietnam. The results will provide important data on the diversity of lichens and serve as a basis for assessing the relationship between the biological characteristics of lichens and the presence of air pollutants in different habitats, the ability of lichens to accumulate environmental pollutants, and the use of lichens to monitor air quality, especially in the large cities and industrial areas of Vietnam.

2. Materials and Methods

2.1. Study Sites

Hanoi is the capital of Vietnam, with a total area of around 3360 km^2 and a population of about 8.4 million people. It is one of the most developed cities in Vietnam, with an urbanization rate of 60%. The average altitude of Hanoi is 5–20 m above sea level; the hills are concentrated in the north and west with the Ba Vi peak the highest at 1281 m. The average annual temperature is 24.9° C, the average humidity is 80–82%, and the average rainfall is over 1700 mm per year (about 114 rainy days per year).

Hanoi also has nine industrial parks and 7.8 million vehicles, including cars and motorbikes. Based on natural conditions and socioeconomic development, we divided and selected typical habitats including forests (TN), industrial parks (CN), urban areas (DT) and rural areas (NN), and roadsides (GT) for lichen sample collection. The locations of the sampling sites are shown in Figure 1.

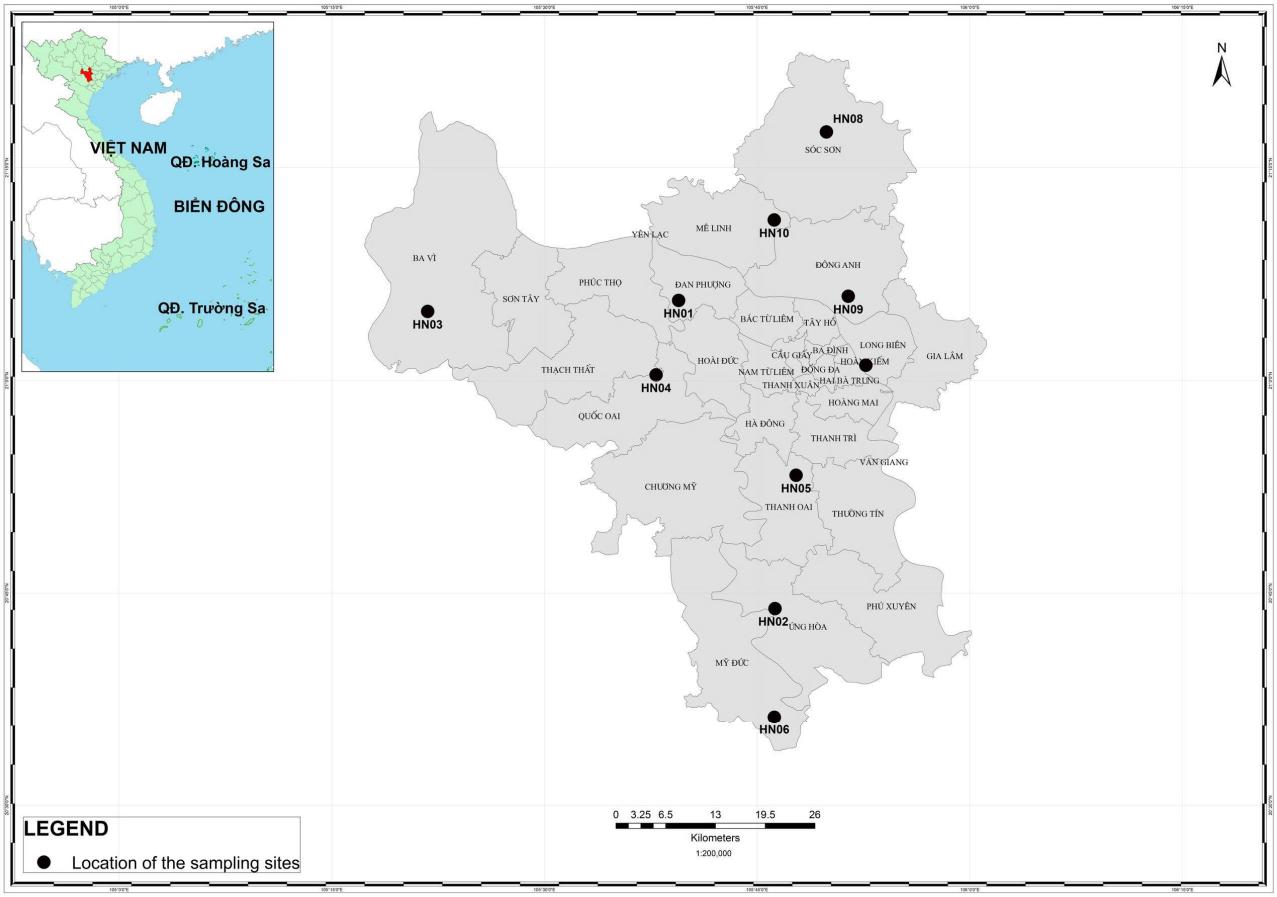

Figure 1. Geographical position of Hanoi and location of sampling sites.

The observed climatic and environmental characteristics of the sampling sites are presented in Table 1.

Table 1. Environmental conditions of the sampling sites.

No.	Sampling Sites	Landscapes	Latitude (°N)	Longitude (°E)	Temperature (°C)	Relative Humidity (%)	$PM_{2.5}$ ($\mu g/m^3$)	NO_2 ($\mu g/m^3$)	SO_2 ($\mu g/m^3$)
1	Cầu Gáo industrial park	CN	21.093637	105.656982	32	60	84	35.595	46.238
2	Van Dinh town	DT	21.106552	105.538488	30	62	40	20.051	39.285
3	Ba Vi national park	TN	21.083683	105.371891	25	88	2	2.176	14.949
4	Thach That industrial park	CN	21.006415	105.631266	33	58	42	15.388	28.856
5	Southern traffic axis	GT	21.098805	105.857090	32	55	48	13.057	33.723
6	Chua Huong heritage	TN	20.604024	105.770221	28	82	13	9.948	27.465
7	Long Bien rural area	NN	20.998762	105.944736	31	62	30	15.388	28.856
8	Den Giong temple	TN	21.291945	105.831473	28	70	34	11.502	21.207
9	Hoang Sa road	GT	21.098805	105.857090	33	54	47	37.149	43.457
10	Quang Minh industrial park	CN	21.188471	105.770051	30	62	70	44.921	61.535

2.2. Lichen Sampling and Identification

Survey lines were established in the sampling sites according to Giordani et al. (2013) [31]. On each survey line, four sampling points were established. Each point was 200–2000 m apart, depending on the terrain conditions to ensure changes in air pollution factors. The total number of sampling plots for five habitats was 200. The sampling was conducted during 30 April 2023–4 May 2023.

Lichen sampling was carried out according to Gradstein et al. (1996) [32], Alexander (2013) [6], Giordani and Brunialti (2015) [31], and Khastini (2019) [33]. At each sampling point, four host trees of 10 cm diameter at breast height were chosen for lichen sampling. Lichen samples on the trunk were collected at a height of 1–2 m above the ground. The host trees included *Litchi chinensis* Sonn., and *Psidium guajava* L. (in rural areas); *Terminalia catappa* L., *Lagerstroemia speciosa* (L.) Pers., *Delonix regia* (Bojer ex Hook.) Raf., and *Cinnamomum camphora* (L.) J. Presl (in industrial parks, urban areas, and roadsides); and *Michelia cavaleriei* (Finet & Gagnep.) Figlar, *Amentotaxus argotaenia* (Hance) Pilg., *Michelia mediocris* Dandy, *Paramichelia baillonii* (Pierre) Hu, *Aquylaria crassna* Pierre, and *Madhca pasquieri* (Dubard) H. J. Lam, 1925 (in forests). For lichens on leaves, 3–5 leaves with the most lichens were collected. The collected samples were placed in paper bags and then stored in cool places for further analysis. We periodically checked and changed the paper bags to avoid moisture or mold development.

Lichen identification was carried out by observing anatomical sections of the thallus and fruiting bodies using stereoscopic and optical microscopes, according to Gradstein et al. (2003) [32], Lücking (2009) [34], and Orange (2010) [35]. The external characteristics of the lobes such as the color and thallus aspect, the width and length of the lobes, the presence of pycnidia, and the aspect of the rhizines, ciliates, and apothecia were also analyzed. The lichen species were identified according to Bungartz et al. (2003) [36], Kelly (2006) [37], and Lücking (2009) [34].

Sorensen's species similarity index (SI) was used to assess the similarity of lichen communities at the 5 study landscapes. The SI was calculated according to Sorensen (1948) [38]: $SI = 2C/(A + B)$, where C is the number of lichen species in both landscapes A and B; A and B are the numbers of lichen species in landscapes A and B, respectively.

3. Results

3.1. Lichen Diversity of Hanoi

A total of 67 lichen species belonging to 16 families and 8 orders were collected from different land covers/land uses in Hanoi (Table 2).

Table 2. Lichen taxa collected in Hanoi.

No.	Species	Families	Orders	Landscapes
1	*Arthonia caribaea* (Ach.) A. Massal.	Arthoniaceae	Arthoniales	DT
2	*Arthonia catenatula* Nyl.	Arthoniaceae	Arthoniales	GT
3	*Arthonia cinnabarina* (DC.) Wallr	Arthoniaceae	Arthoniales	CN, TN
4	*Arthonia didyma* Körber	Arthoniaceae	Arthoniales	DT, GT
5	*Arthonia excipienda* (Nyl.) Nyl.	Arthoniaceae	Arthoniales	TN
6	*Arthonia parantillarum* Aptroot	Arthoniaceae	Arthoniales	GT
7	*Arthonia punctiformis* Ach.	Arthoniaceae	Arthoniales	TN
8	*Arthonia spadicea* Leight.	Arthoniaceae	Arthoniales	GT, TN
9	*Cryptothecia* sp.	Arthoniaceae	Arthoniales	TN
10	*Cryptothecia striata* Thor	Arthoniaceae	Arthoniales	TN
11	*Amandinea punctata* (Hoffm.) Coppins & Scheid.	Caliciaceae	Caliciales	TN
12	*Amandinea* sp.	Caliciaceae	Caliciales	GT
13	*Dirinaria applanata* (Fée) D.D.Awasthi	Caliciaceae	Caliciales	CN, TN
14	*Dirinaria picta* (Sw.) Clem. & Schear	Caliciaceae	Caliciales	DT, NN, TN
15	*Dirinaria* sp.	Caliciaceae	Caliciales	CN
16	*Leptogium cyanescens* (Ach.) Körb.	Collemataceae	Peltigerales	TN
17	*Chapsa cinchonarum* (Fée) Frisch	Graphidaceae	Ostropales	GT
18	*Diorygma antillarum* (Vain.) Nelsen, Lücking & Rivas Plata	Graphidaceae	Ostropales	TN
19	*Fissurina dumastii* Fée	Graphidaceae	Ostropales	TN
20	*Fissurina elaiocarpa* (A.W. Archer) A.W. Archer	Graphidaceae	Ostropales	TN
21	*Glyphis scyphulifera* (Ach.) Staiger	Graphidaceae	Ostropales	GT, TN
22	*Graphina anguina* (Mont.) Müll.Arg.	Graphidaceae	Ostropales	TN
23	*Graphis aperiens* Müll. Arg	Graphidaceae	Ostropales	DT, TN
24	*Graphis arbusculaeformis* (Vain.) Lücking	Graphidaceae	Ostropales	GT, TN
25	*Graphis caesiella* Vain.	Graphidaceae	Ostropales	CN, GT, TN
26	*Graphis crebra* Vain	Graphidaceae	Ostropales	CN
27	*Graphis duplicata* Ach.	Graphidaceae	Ostropales	TN
28	*Graphis handelii* Zahlbr	Graphidaceae	Ostropales	TN
29	*Graphis lineola* Ach	Graphidaceae	Ostropales	CN, DT, GT, NN
30	*Graphis mokanarum* Lücking, Moncada & M.C. Martínez	Graphidaceae	Ostropales	TN
31	*Graphis rimulosa* (Mont.) Trevis.	Graphidaceae	Ostropales	GT, TN
32	*Graphis schiffneri* (Zahlbr)	Graphidaceae	Ostropales	DT
33	*Graphis scripta* (L.) Ach.	Graphidaceae	Ostropales	CN, DT, TN
34	*Herpothallon sipmanii* Aptroot, Lücking & Rivas Plata	Graphidaceae	Ostropales	NN, TN
35	*Leucodecton compunctum* (Ach.) A. Massal.	Graphidaceae	Ostropales	TN
36	*Ocellularia papillata* (Leight.) Zahlbr.	Graphidaceae	Ostropales	TN
37	*Phaeographis eludens* (Stirt.) Shirley	Graphidaceae	Ostropales	DT

Table 2. *Cont.*

No.	Species	Families	Orders	Landscapes
38	*Haematomma erythromma* (Nyl.) Zahlbr.	Haematommataceae	Lecanorales	TN
39	*Opegrapha viridis* (Ach.) Behlen & Desberger	Lecanographaceae	Arthoniales	TN
40	*Lecanora helva* Stizenb.	Lecanoraceae	Lecanorales	DT, GT
41	*Lecanora leprosa* (Fée)	Lecanoraceae	Lecanorales	CN
42	*Lecanora* sp.	Lecanoraceae	Lecanorales	GT
43	*Malmidea vinosa* (Eschw.) Kalb, Rivas Plata & Lumbsch	Malmideaceae	Lecanorales	TN
44	*Bulbothrix isidiza* (Nyl.) Hale	Parmeliaceae	Lecanorales	TN
45	*Parmelia sulcata* Taylor	Parmeliaceae	Lecanorales	TN
46	*Verseghya thysanophora* Harris	Pertusariaceae	Pertusariales	NN
47	*Pertusaria albescens* (Huds.) M.Choisy & Werner	Pertusariaceae	Pertusariales	DT
48	*Pertusaria leioplaca* (Ach.) DC.	Pertusariaceae	Pertusariales	TN
49	*Pertusaria rupicola* (Fr.) Harm.	Pertusariaceae	Pertusariales	GT
50	*Porina byssophila* (Hepp) Zahlbr.	Porinaceae	Ostropales	TN
51	*Porina distans* Vězda & Vivant	Porinaceae	Ostropales	TN
52	*Porina eminentior* (Nyl.) P.M. McCarthy	Porinaceae	Ostropales	TN
53	*Porina* sp.	Porinaceae	Ostropales	TN
54	*Porina tetracerae* (Ach.) Müll.Arg.	Porinaceae	Ostropales	TN
55	*Lithothelium* sp.	Pyrenulaceae	Pyrenulales	TN
56	*Pyrenula nitida* (Weigel) Ach.	Pyrenulaceae	Pyrenulales	TN
57	*Pyrenula nitidella* (Flörke) Müll. Arg.	Pyrenulaceae	Pyrenulales	CN
58	*Pyrenula* sp.	Pyrenulaceae	Pyrenulales	CN
59	*Biatora pontica* Printzen & Tønsberg	Ramalinaceae	Lecanorales	TN
60	*Biatora* sp.	Ramalinaceae	Lecanorales	NN
61	*Dichosporidium nigrocinctum* (Ehrenb.) G.Thor	Roccellaceae	Arthoniales	TN
62	*Sagenidiopsis isidiata* G. Thor, Elix, Lücking & Sipman	Roccellaceae	Arthoniales	TN
63	*Syncesia* sp.	Roccellaceae	Arthoniales	GT
64	*Lepraria arbuscula* (Nyl.) Lendemer & Hodk.	Stereocaulaceae	Lecanorales	TN
65	*Lepraria incana* (L.) Ach.	Stereocaulaceae	Lecanorales	GT, TN
66	*Lepraria* sp.	Stereocaulaceae	Lecanorales	DT
67	*Trypethelium ochroleucum* (Eschw.) Nyl.	Trypetheliaceae	Trypetheliales	DT

The distribution of the lichen taxa collected from different landscapes was uneven (Figure 2). Most taxa were from natural forests with 43 species (64.2% of total species), seven orders (87.5% of total orders), and 14 families (87.5% of the total lichen families collected), followed by roadsides with 15 species (22.4%), six orders (75.0%), and 7 families (43.8%); urban areas with 12 species (17.9%), seven orders (87.5%), and 8 families (50.0%); industrial areas with 10 species (14.9%), seven orders (87.5%), and 7 families (43.8%); and rural areas with 5 species (7.5%), four orders (50.0%), and 5 families (25.0%).

The study results also highlighted that there were five families with only 1 species, two families with 2 species, seven families with 3–5 species, one family with 10 species, and one family with 21 species. The family with the highest number of lichen species was Graphidaceae (21 species), followed by Arthoniaceae (10 species) and Caliciaceae and Porinaceae (5 species) (Figure 3).

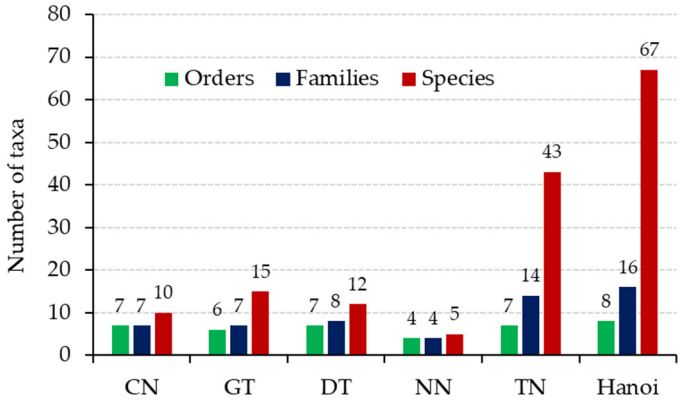

Figure 2. Lichen taxa distribution in different landscapes.

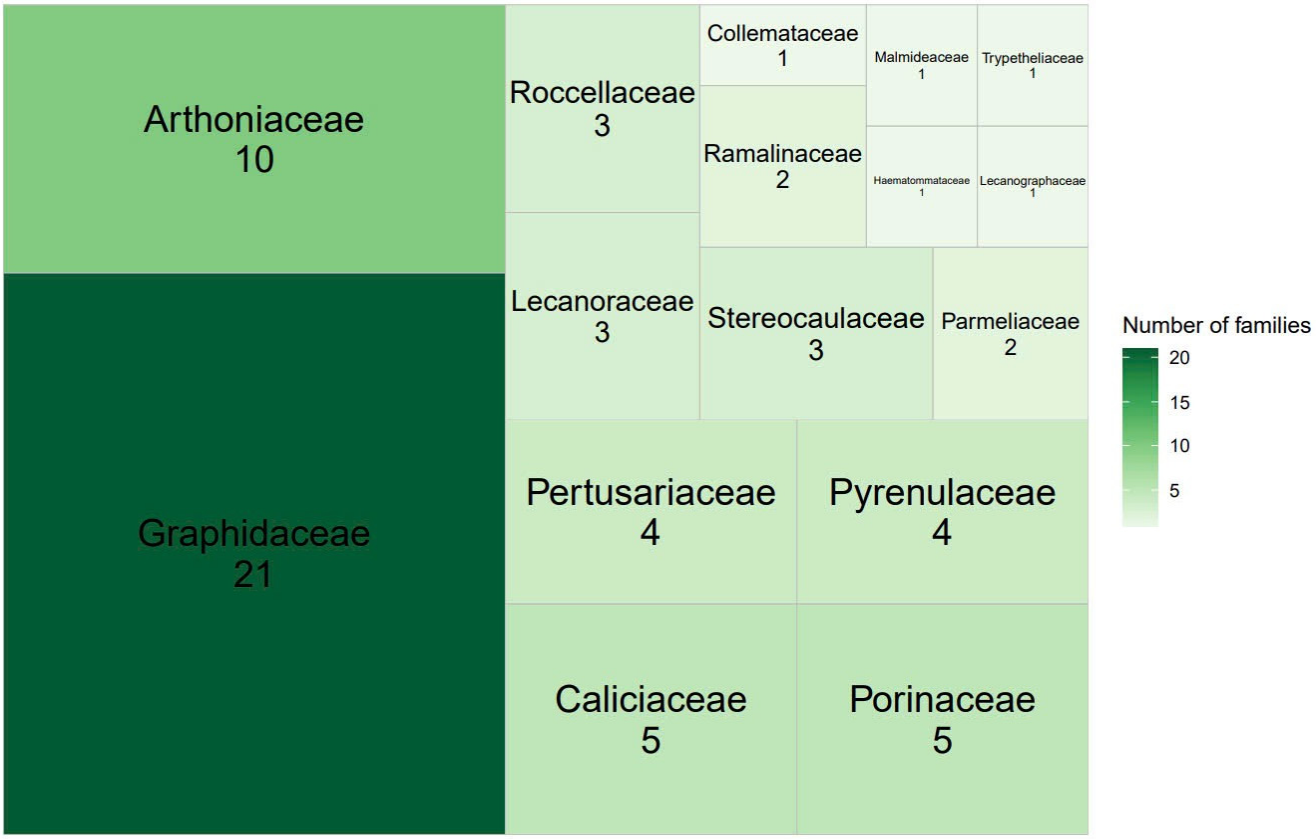

Figure 3. Diversity of lichen families sampled in Hanoi.

3.2. Lichen Distribution in Hanoi

There were differences in species distribution among landscapes. Of the 52 species that were specific to a single landscape, 32 species occurred only in the natural forests, 7 species were collected from roadsides, 6 species were collected from urban areas, 5 species were collected from industrial areas, and 2 species were collected from rural areas. One species, *Graphis lineola* Ach, occurred in four landscapes of urban, industrial, and rural areas and roadsides. Five species found in the urban areas occurred in one or two other landscapes as well. Of those species, *Graphis scripta* (L.) Ach. was found in urban and industrial areas and natural forests; *Dirinaria picta* (Sw.) Clem. & Schear was found in urban and rural areas and natural forests; *Graphis aperiens* Müll. Arg was found in both rural areas and natural forests; and two other species were found in both urban areas and roadsides: *Arthonia didyma*

(Gustav Wilhelm Körber) and *Lecanora helva* Stizenb. (Table 1). The spatial distribution of those species in different sampling sites is also presented in Figure 4.

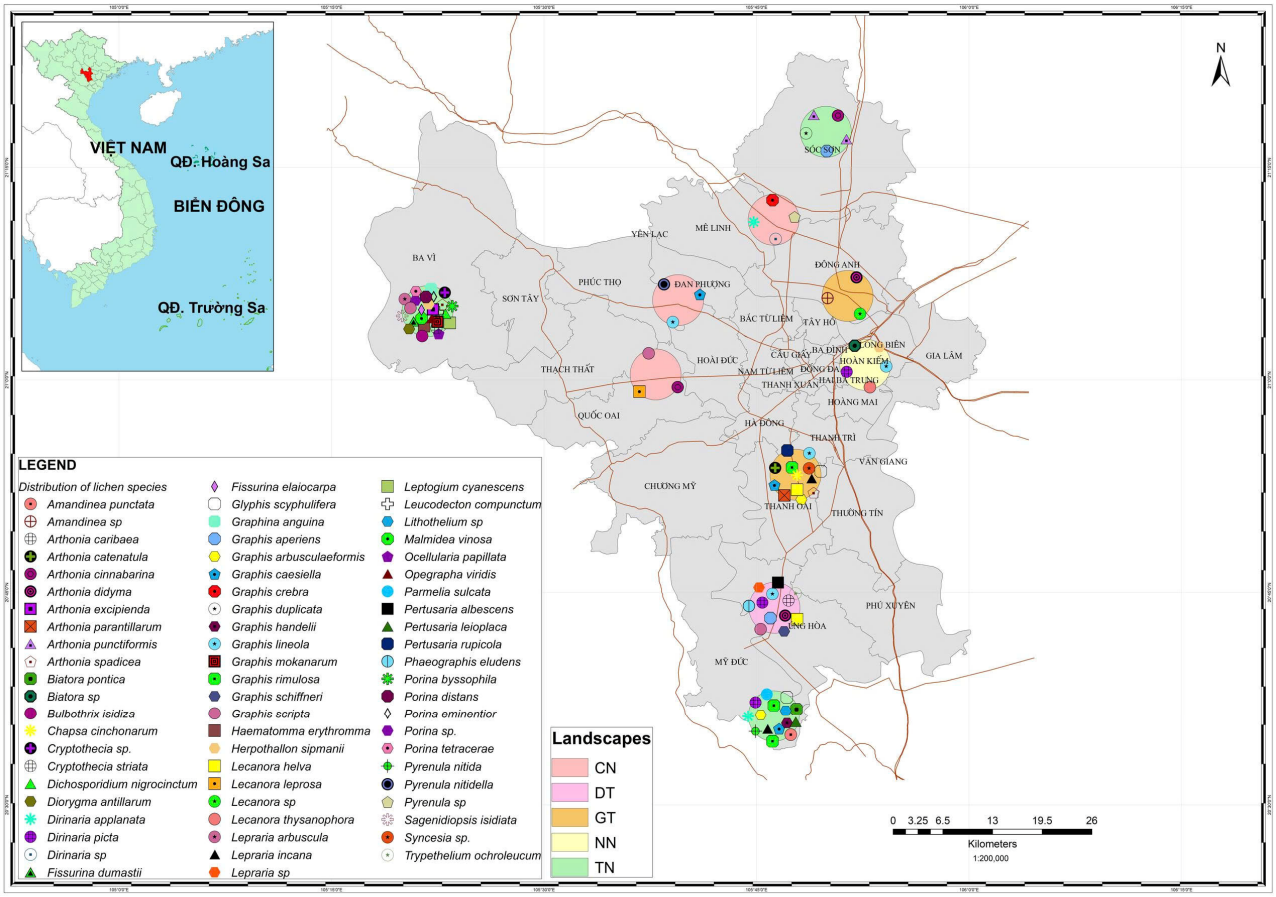

Figure 4. Distribution of lichen species in different landscapes in Hanoi.

3.3. The Similarity Index Among Sampling Sites in Hanoi

The Similarity Index (Table 3) shows how the landscapes differed according to the presence or absence and abundance of lichen species. The similarity between roadsides and natural forests (28.57%) was higher than for urban areas and roadsides (20.00%) or for industrial areas and natural forests (19.05%). Rural areas and industrial areas, and rural areas and roadsides had the lowest similarity (less than 10%).

Table 3. Similarity Index among different landscapes.

	CN	GT	DT	NN	TN
CN		0.1429	0.1333	0.0909	0.1905
GT	0.1429		0.2000	0.0909	0.2857
DT	0.1333	0.2000		0.1667	0.1364
NN	0.0909	0.0909	0.1667		0.1111
TN	0.1905	0.2857	0.1364	0.1111	

4. Discussion

Lichen species that belong to the Graphidaceae and Caliciaceae families were present in all landscapes (rural, urban, and industrial areas, roadsides, and natural forests), but the specific species differed. For example, among the Graphidaceae, *Graphis schiffneri* Zahlbr and *Phaeographis eludens* (Stirt.) Shirley were present only in urban areas, while *Graphis crebra* Vain of the Graphidaceae family and *Dirinaria* sp. of the Caliciaceae family were

found only in industrial areas, and *Chapsa cinchonarum* (Fée) Frisch of the Graphidaceae family and *Amandinea* sp. of the Caliciaceae family were found only on roadsides. On the other hand, *Diorygma antillarum* (Vain.) Nelsen, Lücking & Rivas Plata, *Fissurina dumastii* Fée, *Fissurina elaiocarpa* (A.W. Archer) A.W. Archer, *Graphina anguina* (Mont.) Müll.Arg., *Graphis duplicata* Ach., *Graphis handelii* Zahlbr, *Graphis mokanarum* Lücking, Moncada & M.C. Martínez, *Leucodecton compunctum* (Ach.) A. Massal., *Ocellularia papillata* (Leight.) Zahlbr., *Haematomma erythromma* (Nyl.) Zahlbr., and *Opegrapha viridis* (Ach.) Behlen & Desberger (all Graphidaceae) were present only in natural forests. Similarly, *Amandinea punctata* (Hoffm.) Coppins & Scheid. of the Caliciaceae family was also found only in natural forests (Table 2). These differences can be explained by the differing environmental factors in the landscapes. For example, industrial and urban areas and roadsides are concentrated in the city center, which are vulnerable to air pollution and human activities. Anthropogenic activities lead to increased levels of nitrogen and sulfur compounds in the atmosphere, and only acidophile and nitrophile types of lichens can survive under high concentrations of these elements. Species of the families Parmeliaceae, Porinaceae, and Collemataceae were present only at high altitudes (Huong Son and Ba Vi national park) (Figure 4). These three families are foliose-type lichens, which only grow at low temperatures in areas of high humidity. A study by Sipman (2009) [39] concluded that foliose-type lichens can grow abundantly at higher altitudes in regions with tropical climates. In addition, most of the Parmeliaceae, such as *Malmidea vinosa* (Eschw.) Kalb, Rivas Plata & Lumbsch, *Bulbothrix isidiza* (Nyl.) Hale, and *Parmelia sulcata* Taylor, are highly sensitive to air pollution, which is why these species are found commonly only in natural forests.

Our results show that in urban, industrial, and traffic-intensive areas, the lichen species diversity and lichen community composition are reduced. Differences in species composition in different habitats may influence lichen distribution, but it is clear that in these habitats, compared to natural forest habitats, the significantly poor quality of the air containing high levels of pollutants may be the main reason for the significantly lower lichen species composition in these areas. Similarly, agricultural habitats with fruit trees and frequent human interventions that may include pesticides are also responsible for the significantly lower lichen species diversity and composition in these habitats compared to natural ones. These results also suggest the need for further studies to more fully assess the relationship between lichen diversity and species composition and air quality in their distribution areas, thereby considering the possibility of using lichens as air environment indicators.

Author Contributions: Conceptualization, H.N.K. and B.T.T.; methodology, H.N.K., B.T.T. and V.T.P.G.; validation, H.N.K., N.T.H.H., N.T.H.L. and V.T.P.G.; formal analysis, L.D.T. and H.N.K.; investigation, H.N.K., L.D.T., N.T.H.H., N.T.H.L., N.Q.B., V.T.P.G., P.H.T. and B.T.T.; data curation, H.N.K., B.T.T., L.D.T. and P.H.T.; writing—original draft preparation, H.N.K. and B.T.T.; writing—review and editing, H.N.K., L.D.T., N.T.H.H., N.T.H.L., N.Q.B., V.T.P.G., P.H.T. and B.T.T.; visualization, L.D.T. and P.H.T.; supervision, N.T.H.H., N.Q.B. and V.T.P.G.; funding acquisition, H.N.K. All authors have read and agreed to the published version of the manuscript.

Funding: This work is supported by Vietnam Ministry of Natural Resources and Environments through project TNMT.2022.562.05.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: Most of the raw data can be accessed by contacting the corresponding author, as the data are still under processing for further publications.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Spribille, T.; Tuovinen, V.; Resl, P.; Vanderpool, D.; Wolinski, H.; Aime, M.C.; McCutcheon, J.P. Basidiomycete yeasts in the cortex of ascomycete macrolichens. *Science* **2016**, *353*, 488–492. [CrossRef] [PubMed]
2. McKane, L.; Kandel, J. *Microbiology: Essentials and Applications*, 2nd ed.; McGraw-Hill: New York, USA, 1996.
3. Dobson, F.S. *Lichens: An Illustrated Guide to the British and Irish Species*; Richmond: Slough, UK, 2011.
4. Dahlman, L.; Palmqvist, K. Growth in two foliose tripartite lichens, Nephroma arcticum and Peltigera aphthosa: Empirical modelling of external vs. internal factors. *Funct. Ecol.* **2003**, *17*, 821–831. [CrossRef]
5. Hale, M.E. *The Biology of Lichens*; Edward Arnold: London, UK, 1983.
6. Alexander, K.E. Morphological Changes and Damages of Indicator Lichens from Sakhalin Island. *Mod. Phytomorphol.* **2013**, *4*, 215–216. [CrossRef]
7. Conti, M.E.; Cecchetti, G. Biological monitoring: Lichens as bioindicators of air pollution assessment—A review. *Environ. Pollut.* **2001**, *114*, 471–492. [CrossRef]
8. Rope, S.; Pearson, L. Lichens as air pollution biomonitors in a semiarid environment in Idaho. [*Lecanora melanophthalma* (Ram.); Artemisia tridentata]. *Bryologist* **2009**, *93*, 50–61. [CrossRef]
9. Richardson, D.H.S. *Pollution Monitoring with Lichens*; Richmond Publishing Company: London, UK, 1992.
10. Nash, T.H.; Gries, C. Lichens as Indicators of Air Pollution. In *Air Pollution*; Springer: Berlin/Heidelberg, Germany, 1991; pp. 1–29. [CrossRef]
11. Pinho, P.; Augusto, S.; Branquinho, C.; Bio, A.; Pereira, M.J.; Soares, A.; Catarino, F. Mapping Lichen Diversity as a First Step for Air Quality Assessment. *J. Atmos. Chem.* **2004**, *49*, 377–389. [CrossRef]
12. Jovan, S. *Lichen Bioindication of Biodiversity, Air Quality, and Climate: Baseline Results from Monitoring in Washington, Oregon, and California*; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: Corvallis, OR, USA, 2008.
13. Will-Wolf, S. *Analyzing Lichen Indicator Data in the Forest Inventory and Analysis Program*; U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: Corvallis, OR, USA, 2010.
14. Gadsdon, S.R.; Dagley, J.R.; Wolseley, P.A.; Power, S.A. Relationships between lichen community composition and concentrations of NO_2 and NH_3. *Environ. Pollut.* **2010**, *158*, 2553–2560. [CrossRef]
15. Müller-Argoviensis, L. Lichenes tonkinensis, a Cl. Balansa lecti. *Hedwigia* **1891**, *30*, 181–189.
16. Hue, A. Lichenes Extra-Europaei a pluribus collectoribus ad Museum Parisiense missi. *Nouv. Arch. Mus. D'histoire Nat.* **1901**, *3*, 21–146.
17. Schmid, M. *Vegetation du Viet-Nam: Le Massif Sud-Annamitique et les Regions Limitrophes*; ORSTOM: Paris, France, 1974.
18. Tixier, P. *Flore et Végétation Orophiles de l'Asie Tropicale: Les Epiphytes du Flanc Méridional du Massif Sud Annamitique*; Société d'édition d'enseignement Supérieur: Paris, France, 1966.
19. Pham, H.H. *An Illustrated Flora of Vietnam (Part I)*; NXB Tre: Hanoi, Vietnam, 1999.
20. Vo, T.P.G. New records of lichens from Vietnam. *Sci. Technol. Dev.* **2009**, *12*, 54–60. [CrossRef]
21. Nguyen, T.T.; Joshi, Y.; Dzung, N.A.; Hur, J.-S. First report of a fertile specimen of Coenogonium disciforme: A species new to the Vietnamese lichen flora. *Lichenologist* **2011**, *43*, 184–186. [CrossRef]
22. Nguyen, T.T.; Joshi, Y.; Lücking, R.; Nguyen, A.D.; Wang, X.Y.; Jin Koh, Y.; Hur, J.-S. Seven new records of foliicolous lichens from Vietnam. *Mycotaxon* **2011**, *117*, 93–99. [CrossRef]
23. Nguyen, T.T.; Joshi, Y.; Lücking, R.; Wang, X.-Y.; Dzung, N.A.; Koh, Y.-J.; Hur, J.-S. Notes on Some New Records of Foliicolous Lichens from Vietnam. *Taiwania* **2010**, *55*, 402–406.
24. Jayalal, U.; Aptroot, A.; Nguyen, T.T.; Dzung, N.A.; Joshi, S.; Oh, S.-O.; Hur, J.-S. Further additions to the macrolichen mycota of Vietnam. *Mycotaxon* **2013**, *124*, 51–59. [CrossRef]
25. Joshi, S.; Jayalal, U.; Oh, S.-O.; Nguyen, T.T.; Dzung, N.A.; Hur, J.-S. The lichen genus Graphis from Vietnam. *Mycotaxon* **2013**, *125*, 69–80. [CrossRef]
26. Joshi, S.; Nguyen, T.T.; Dzung, N.A.; Jayalal, U.; Oh, S.-O.; Hur, J.-S. New records of corticolous lichens from Vietnam. *Mycotaxon* **2013**, *123*, 479–489. [CrossRef]
27. Joshi, S.; Nguyen, T.T.; Dzung, N.A.; Jayalal, U.; Oh, S.-O.; Hur, J.-S. The lichen genus Fissurina (Graphidaceae) in Vietnam. *Mycotaxon* **2013**, *124*, 309–321. [CrossRef]
28. Dung, N.T.M. *Nghiên cứu Thành Phần hoá học của hai loài địa y Lobaria Orientalis và Dendriscosticta Platyphylloides (Lobariaceae)*; University of Science, VNU HCMC: Ho Chi Minh City, Vietnam, 2013.
29. Thai, K.D.; Hoang, T.H.T. Study on the accumulation of metals in bioindicator by neutron activation analysis. *Ho Chi Minh City Univ. Educ. J. Sci.* **2008**, *14*, 104–110.
30. Nguyen, T.L. *Địa y và đài thực vật phụ sinh trên thân cây với thực trạng không khí ở TP. HCM.*; Ho Chi Minh City Department of Science and Technology: Ho Chi Minh City, Vietnam, 2020.

31. Giordani, P.; Brunialti, G. Sampling and Interpreting Lichen Diversity Data for Biomonitoring Purposes. In *Recent Advances in Lichenology: Modern Methods and Approaches in Biomonitoring and Bioprospection*; Upreti, D.K., Divakar, P.K., Shukla, V., Bajpai, R., Eds.; Springer: New Delhi, India, 2015; Volume 1, pp. 19–46. [CrossRef]
32. Gradstein, S.R.; Nadkarni, N.M.; Krömer, T.; Holz, I.; Nöske, N. A protocol for rapid and representative sampling of vascular and non-vascular epiphyte diversity of tropical rain forests. *Selbyana* **2003**, *24*, 105–111.
33. Khastini, R.; Sari, I.; Herysca, Y.; Sulasanah, S. Lichen diversity as indicators for monitoring ecosystem health in Rawa Danau Nature Reserve, Banten, Indonesia. *Biodiversitas* **2019**, *20*, 489–496. [CrossRef]
34. LÜCking, R.; Archer, A.W.; Aptroot, A. A world-wide key to the genus Graphis (Ostropales: Graphidaceae). *Lichenologist* **2009**, *41*, 363–452. [CrossRef]
35. Orange, A.; James, P.W.; White, F.J. *Microchemical Methods for the Identification of Lichens*; British Lichen Society: London, UK, 2010.
36. Bungartz, F.; Nash Iii, T.; Rosentreter, R. *Field Guide to Common Epiphytic Macrolichens in Arizona—An identification Manual for the USDA Forest Inventory and Analysis Program*; USDA Forest Service & Arizona State University Lichen Herbarium: Tempe, AZ, USA, 2002.
37. Kelly, A.M. *Guide to Common Macrolichens and Bryophytes of the Umatilla National Forest*; United States Department of Agriculture: Washington, DC, USA, 2006.
38. Sorensen, T. A Method of Establishing Groups of Equal Amplitude in Plant Sociology Based on Similarity of Species Content and Its Application to Analyses of the Vegetation on Danish Commons. *Biol. Skr./K. Dan. Vidensk. Selsk.* **1948**, *5*, 1–34.
39. Sipman, H.J.M. Tropical urban lichens: Observations from Singapore. *Blumea Biodivers. Evol. Biogeogr. Plants* **2009**, *54*, 297–299. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.