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TAXONOMIC DIVERSITY OF LICHENS OF A PROTECTED AREA IN AN INDUSTRIAL CITY (AS AN EXAMPLE OF THE CITY OF DNIPRO, UKRAINE)

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Abstract

The aim of this study is to inventory the taxonomic diversity of lichens in the territory of the protected area of local importance "Novokodatskyi Park" located within the large industrial city of Dnipro (Dnipro region, Ukraine), taking into account the data of automated air monitoring. Along with the development of instrumental methods for studying the state of environmental components, biological monitoring is also relevant. After all, living organisms, namely their taxonomic diversity, number and its dynamics, etc., are integral indicators of the state of the environment. Numerous species of organisms are widely used as biomonitors of air pollution, the most famous of which are lichens, as it has been found that with an increase in the content of pollutants in the air, bushy, then leafy and finally scaling forms of lichens first disappear. Numerous studies have also shown a correlation between the number of lichen species and increased concentrations of pollutants in the air. The city of Dnipro is one of the largest industrial cities in Ukraine and has a high level of technogenic load. There are 10 industrial facilities of national and regional significance within the city of Dnipro, which are included in the List of the most environmentally hazardous facilities, and the largest metallurgical enterprises are concentrated in the Novokodatskyi district of Dnipro. During the survey of the territory of the Novokodatskyi Park, a nature reserve of local importance, 10 species of lichens from 6 families were registered. Let's believe that the study of the taxonomic diversity of the lichen biota of large industrial cities and other settlements is a promising area of research in terms of lichen indication. After all, in this case, lichen diversity is an integral indicator, and the results obtained are quite clear.

Keywords: lichen, lichens diversity, lichen indication, bioindication, biomonitoring, ecological indicator, industrial city, air pollution, air quality, urban area.

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1. Introduction

Air pollution is an acute problem both in the world in general [1] and in Ukraine in particular [2–5]. Monitoring the state of environmental components today is an integral part of the existence and development of human settlements. This is especially true for technologically loaded areas with a high concentration of industrial facilities (stationary emission sources) and transport (mobile emission sources).

According to the study [2], Dnipro region is one of the most affected regions of Ukraine by air pollution, and the city of Dnipro is one of the most polluted cities. This is demonstrated by the data presented in this paper on the main statistical indicators of certain pollutants obtained as a result of remote monitoring by the European satellite mission Sentinel-5P, as well as data from the main European models provided by the European Center for Medium-Range Weather Forecasting (ECMWF). Where Dnipro region is noted as a region with ultra-high concentrations of nitrogen dioxide, carbon monoxide, sulfur dioxide, fine particulate matter PM2.5 and PM10.

This is due to the fact that Dnipropetrovsk region is a powerful industrial region with numerous industrial enterprises in the mining and metallurgical, fuel and energy, chemical, and other sectors [6].

It is worth noting that a regional automated air monitoring system is currently operating in the Dnipro region, implemented by the Environmental Monitoring Center of the Dnipro Regional Council.

However, along with the development of instrumental methods for studying the state of environmental components, biological monitoring is also relevant. After all, living organisms, namely their taxonomic diversity, number and its dynamics, etc., are integral indicators of the state of the environment.

Numerous species of organisms are widely used as biomonitors of air pollution, the most famous of which are lichens [7]. Lichens are able to respond to air pollutants at different levels [8–10]. This is because lichens are able to absorb mineral forms of nitrogen and other substances from the air. This is what makes lichens highly sensitive to air pollution, namely to the content of such chemical compounds as sulfur dioxide, nitrogen dioxide, ozone, fluorides, and trace elements in the air [11]. Therefore, lichens are used as biomonitors of air pollution in a variety of ways, including lichen biodiversity [12], lichen transplantation methods [13], and physiological changes in lichens [14].

It has also been found that with an increase in the content of pollutants in the air, bushy, then leafy, and finally scaling forms of lichens first disappear [9]. A number of publications have also shown a correlation between the number of lichen species and an increase in the concentration of pollutants in the air [15–17].

The aim of this work is to inventory the taxonomic diversity of lichens in the territory of the protected object of local importance “Novokodatskyi Park” located within the large industrial city of Dnipro (Dnipropetrovsk region, Ukraine), using lichen indication methods based on automated air monitoring data.

2. Materials and methods

The city of Dnipro is one of the largest industrial cities in Ukraine and has a high level of technological pressure. There are 10 industrial facilities of national and regional significance within the city of Dnipro, which are included in the List of the most environmentally hazardous facilities according to the Environmental Passport of the city of Dnipro and which affect the state of the city’s air [18, 19].

The city covers 405 km^2, including 55 % of the built-up area, 30 % of landscape and recreational areas, and 15 % of water and other surfaces [18]. As of January 1, 2022, the population of the city of Dnipro is 968,5 thousand people.

Novokodatskyi district is a western administrative district of the city of Dnipro with an area of 88.7 km^2. As of January 1,2022, the population of Novokodatskyi district amounted to 164.4 thousand people.

It is worth noting that the largest enterprises of the metallurgical complex are concentrated in the Novokodatskyi district of Dnipro, namely Dnipro Metallurgical Plant, Dnipro Pipe Plant, Dnipro Coke Plant, Dnipro Metal Structures Plant, and others. As of 2016, the population of Novokodatskyi district amounted to 164.0 thousand people.

“The Novokodatskyi City Youth Leisure and Recreation Park (hereinafter referred to as the Novokodatskyi Park) is a park-monument of landscape art of local importance in accordance with the decision of the Dnipropetrovsk Regional Executive Committee of 22.06.72 No. 391. This object of the nature reserve fund is located in the Novokodatskyi district of the city of Dnipro and was created for the purpose of protection, preservation and rational use for aesthetic, educational, scientific, environmental and health purposes. In fact, Novokodatskyi Park is the largest green space for three residential areas in the Novokodatskyi district.

The object of the study is the taxonomic diversity of lichens in the protected area of local importance - Novokodatskyi Park. Lichens have been recorded by the route-expedition method in 2022 on various substrates: tree bark, rotten wood, and other substrates. The collected material was processed in the laboratory of the Botanical Garden of the Oles Honchar Dnipro National University. The names of the lichens were given in accordance with Index Fungorum.

The urban groups or five ecological groups of lichens, according to their resistance to urbanization, are given according to [20]:

1) urbanophile (Upl);
2) moderately urban-philic (m-Upl);
3) urban-neutral (Un);
4) moderately urban-phobic (m-Upb);
5) urban-phobic (Upb).

The urban-phobic group includes species characteristic of natural ecosystems that are absent or very rare within compact urban development. Species recorded in areas of the city with a weak or moderate anthropogenic impact are classified as moderately urban-phobic. The urban-neutral group includes species that occur with equal frequency both within dense urban areas and outside them. Species of the moderately urban- philic group are concentrated within dense urban areas. Urbanophile species are indicators of the urbanized environment, and their presence indicates a high level of anthropogenic pressure.

The data on the content of pollutants in the air have been based on open data from the municipal enterprise "Environmental Monitoring Center" of the Dnipro Regional Council. Namely, data from the indicative monitoring station for 2020, which is located about 2 km from the study area. The automated monitoring station is equipped with the following devices: gas analyzer "GA-100" modification $SO_2/NO_2/CO$, gas analyzer "GA-100" modification $H_2S/O_3/NH_3$, mass concentration meter of aerosol particles "RM-100"; gamma radiation detection unit BDBG-09 C, ultrasonic weather station "MS-650".

Tables 1, 2 show the limit values and levels of pollutants used to assess air quality in accordance with the Resolution of the Cabinet of Ministers of Ukraine No. 827 of August 14, 2019.

Table 1
Limit values of pollutants

Averaging period	Pollutant	Limit value, µg/m³
Calendar year	Sulfur dioxide	40
Calendar year	PM 10	40
Calendar year	PM 2.5	25

Table 2
Other levels of pollutants used to assess air quality

Name of the level of pollutants	Pollutant	Purpose of the evaluation	Averaging period	Numerical expression of the level, µg/m³
Critical level	sulfur dioxide	vegetation protection	calendar year	20
Critical level	nitrogen oxides	–	calendar year	30

3. Research results

During the survey of the Novokodatsky Park, a nature reserve of local importance, 10 species of lichens from 6 families have been recorded. The highest species diversity is characterized by the family Parmeliaceae (3 species), the families Teloschistaceae and Physciaceae are represented by two species each. The families Carbonicolaceae, Lecanoraceae, Lecanoromycetidae are represented by 1 species each (**Table 3**).

Studies have been shown that 6 species are crustose, and 4 species are foliose (**Table 4**). No fruticose species, which are most sensitive to air pollution, were found.

The moderately urban-phobic and moderately urban-philic groups of lichens include 2 of the registered species, and 1 each of the urban-phobic and urban-neutral groups (**Table 4**).

Lichens have been found on the bark of living (24 species of trees and shrubs) and dead trees (2 species of trees), processed wood (carved sculptures, fences, parts of the equipment of adventure parks for children, etc.), concrete structures (slabs, curbs, poles), and metal structures (reinforcement of concrete slabs, metal poles).

Table 3
Taxonomic diversity of recorded lichens and their substrates

Family	**Lichen type/substrate**	**Bark of living trees**																								**Bark of dry trees**		**Other sub-strates**		
		Aceraceae		**Anacardiaceae**		**Betulaceae**	**Bignoniaceae**	**Buxales**	**Caesalpiniaceae**	**Cannabaceae**	**Cupressaceae**		**Fabaceae**	**Hippocastanaceae**	**Moraceae**	**Oleacea**		**Pinaceae**		**Rosaceae**			**Salicaceae**		**Ulmaceae**	**Pinaceae**	**Salicaceae**			
		Acer negundo	***Acer platanoides***	***Rhus typhina***	***Cotinus coggygria***	***Betula pendula.***	***Catalpa sp.***	***Buxus sempervirens.***	***Gleditsia triacanthos***	***Celtis occidentalis***	***Thuja occidentalis***	***Juniperus virginiana***	***Robinia pseudoacacia***	***Aesculus hippocastanum***	***Morus alba.***	***Fraxinus exelsior***	***Syringa vulgaris***	***Pinus sylvestris***	***Pinus pallasiana D.Don***	***Prunus cerasus***	***Rosa canina***	***Spiraea sp.***	***Populus nigra***	***Populus alba***	***Ulmus pumila***	***Picea abies***	***Pinus nigra subsp. pallasiana.***	**Treated wood**	**Concrete blocks, pillars**	**Rebar, metal poles**
Carbonicolaceae	*Carbonicola anthracophila* (Nyl.) Bendiksby & Timdal	+	+	–	+	–	+	–	+	–	+		+	–	+	–	–	+	–	–	–	–	+	+	–	–	–	+	+	–
Lecanoraceae	*Lecanora chlarotera* Nyl.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
Lecanoromycetidae	*Scythioria phlogina* (Ach.) S.Y. Kondr., Kärnefelt, Elix, A. Thell & Hur	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
Parmeliaceae	*Flavoparmelia caperata* (L.) Hale	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
	Hypogymnia physodes (L.) Nyl.	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–
	Parmelia sulcata Taylor	+	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	+	–
Physciaceae	*Phaeophyscia ciliata* (Hoffm.) Moberg	–	–	–	–	+	+	–	–	–	+	–	–	–	–	–	–	–	–	–	–	–	–	+	–	–	–	–	–	–
	Physcia adscendens H. Olivier	+	+	+	+	–	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	–	+	+	+	+	+	+
Teloschistaceae	*Calogaya saxicola* (Hoffm.) Vondrák	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	+	–
	Xanthoria parietina (L.) Th. Fr.	+	+	–	–	+	+	–	+	–	–	–	+	+	+	+	+	+	=	+	–	–	+	+	+	+	–	+	+	–

Table 4
Distribution of lichens by bryophyte morphology, substrate habitat, and urban groups

Lichen species	Morphology of the fronds (scaly, leafy and bushy)	Substrate specificity	Sensitivity to atmospheric pollution conditions*	Urban group**
Carbonicola anthracophila (Nyl.) Bendiksby & Timdal	crustose	tree bark	no information	no information
Lecanora chlarotera Nyl.	crustose	tree bark, sometimes stone	no information	m-Upb
Scythioria phlogina (Ach.) S.Y. Kondr., Kärnefelt, Elix, A. Thell & Hur	crustose	stone	no information	no information
Flavoparmelia caperata (L.) Hale	foliose	tree bark, rarely stone	no information	Upb
Hypogymnia physodes (L.) Nyl.	foliose	tree bark	medium sensitive	m-Upb
Parmelia sulcata Taylor	foliose	tree bark	medium sensitive	Un
Phaeophyscia ciliata (Hoffm.) Moberg	foliose	tree bark	no information	no information
Physcia adscendens H. Olivier	foliose	tree bark	the most resistant to dust contamination	m-Upl
Calogaya saxicola (Hoffm.) Vondrák	crustose	stone	no information	no information
Xanthoria parietina (L.) Th. Fr.	foliose	tree bark	the most resistant to dust contamination	m-Upl

*Note: * – given after [11, 21]; ** – given for epiphytic lichens after [20], notation in «Materials and methods».*

It should be noted that among the listed species of substrate trees and shrubs (**Table 3**), not all species are native to the steppe zone of Ukraine (e.g., *Gleditsia triacanthos*, *Catalpa sp*, etc.). This is due to the fact that this territory is a park-monument of landscape art, which includes ornamental and fruit plants.

The largest number of lichen species was recorded on concrete substrates (8 species), 5 species of lichens were recorded on the bark of *Acer negundo* L., 4 species each on treated wood substrates and on the bark of *Catalpa sp.*; 3 species each on the bark of *Acer platanoides* L., *Gleditsia triacanthos* L., *Thuja occidentalis* L., Robinia pseudoacacia L., Morus alba L., *Pinus sylvestris* L., *Populus alba* L., *Populus nigra* L., and *Picea abies* (L.) H.Karst.); 2 species each on the bark of *Cotinus coggygria* Scop, *Ulmus pumila* L.; 1 species each on the bark of *Rhus typhina* L., Buxus sempervirens L., Celtis occidentalis L., Juniperus virginiana L., Pinus nigra *subsp. pallasiana* (Lamb.) Holmboe), *Rosa canina* L., dead *Populus nigra*, and metal structures (**Fig. 1**).

The species *Physcia adscendens* was recorded on 27 substrates, *Xanthoria parietina* – on 18, *Carbonicola anthracophila* – on 13, *Phaeophyscia ciliata* – on 4, *Parmelia sulcata* – on 3, *Hypogymnia physodes* – on 2, *Calogaya saxicola*, *Flavoparmelia caperata*, *Scythioria phlogina* and *Lecanora chlarotera* – on 1 each (**Fig. 2**).

The species *Physcia adscendens* has been recorded on all types of substrates - on the bark of living and dead trees, treated wood, concrete structures and metal structures.

The species *Xanthoria parietina* has been recorded on the following types of substrates: bark of living and dead trees, treated wood, concrete structures.

The species *Carbonicola anthracophila* has been recorded on the following types of substrates: bark of living trees, treated wood, concrete structures.

Phaeophyscia ciliata has been recorded only on the bark of living trees.

The species *Parmelia sulcata* has been recorded on the bark of living and dead trees, concrete structures.

The species *Hypogymnia physodes* has been recorded on the bark of living trees and treated wood.

The species *Calogaya saxicola*, *Flavoparmelia caperata*, *Scythioria phlogina* and *Lecanora chlarotera* have been recorded only on concrete structures.

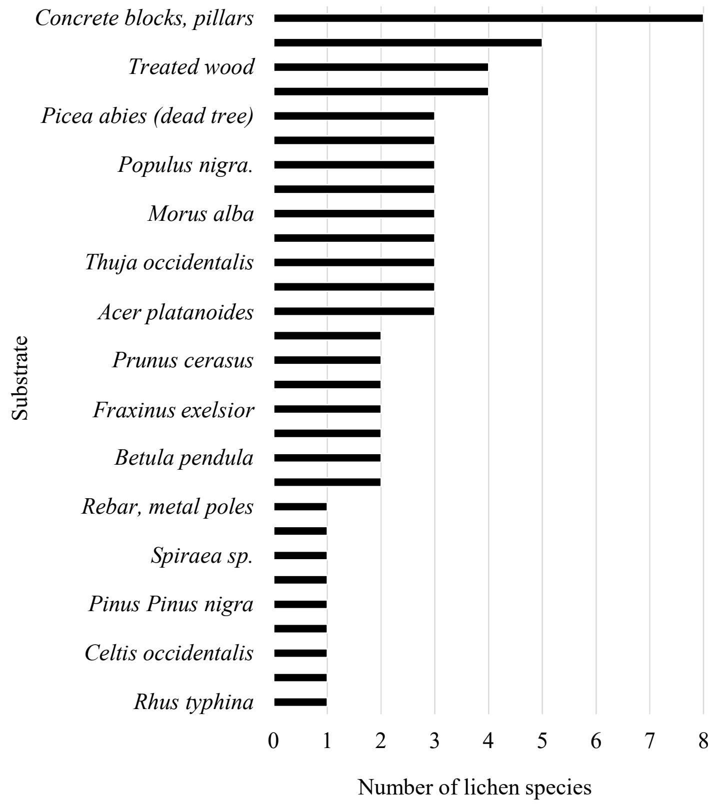

Fig. 1. Number of lichen species on the surveyed substrates in the Novokodatskyi Park

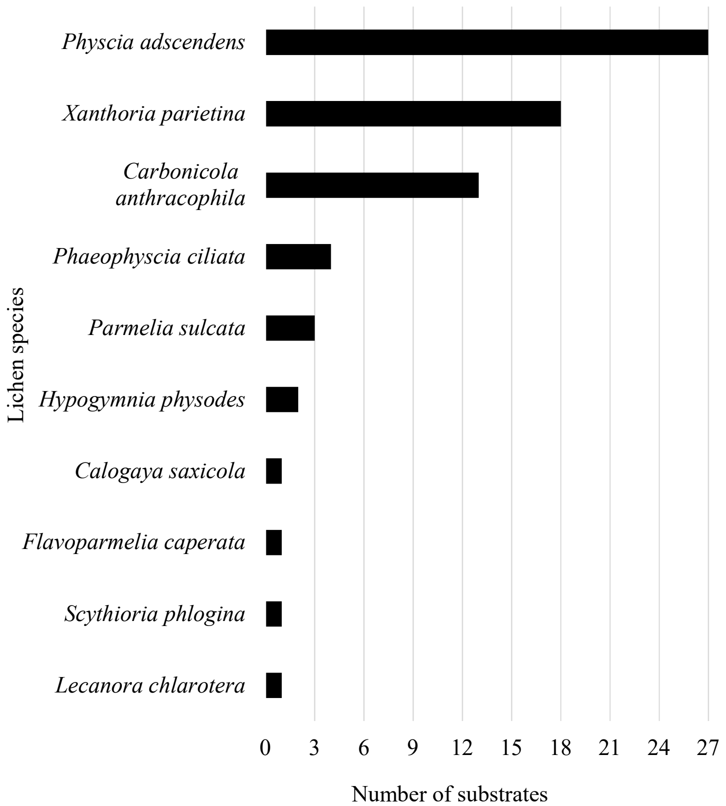

Fig. 2. The number of substrates on which each lichen species found in the Novokodatsky Park has been recorded

It is worth noting that automated air monitoring is actively developing in the Dnipropetrovsk region. Therefore, it is promising to study the spatial distribution of different types of lichens, taking into account the data on the concentration of pollutants and their dynamics in the air.

It should also be borne in mind that, for example, the sample of sulfur dioxide** concentration data (512983 measurements in total) (**Table 5**) contains many zero values (which significantly affects the annual average values), which is most likely due to the sensor's sensitivity threshold rather than the complete absence of sulfur dioxide in the air (which, in our opinion, is true for all pollutants). If to remove the zero values from the sample, 99652 measurements remain in the sample, and the average annual concentration of sulfur dioxide*** is 4.8 times higher, but also does not reach the threshold value.

Table 5

Average annual concentrations of pollutants according to the data of the automated air monitoring station for 2020

Pollutant	Averaging period	Average annual concentration, μg/m³	Maximum concentration values**, μg/m³
NO_2	calendar year	0.41	115.00
SO_2*		2.85**/13.74***	384.00
CO		1124.32	19492.00
O_3		96.16	683.00
H_2S		0.08	80.00
NH_3		48.01	906.00
PM10*		20.29	567.00
PM2.5*		12.50	372.00

*Note: * – limit values are defined for these substances (see the section "Materials and Research Methods");*
*** – average values of pollutant concentrations have been given from a sample of data obtained from measurements every minute (minimum values for all values are zero);*
**** – average values of pollutant concentrations have been given from a sample of data obtained from measurements every minute, but all zero values have been removed from the sample.*

The average annual concentrations were calculated based on open data from the automated air monitoring station of the municipal enterprise "Environmental Monitoring Center of the Dnipro Regional Council". Comparing the results with the limit values, let's note that no exceedances of the limit values have been recorded. However, the maximum values of pollutant concentrations are relatively high (let's also present the monthly dynamics of PM10 and PM 2.5 concentrations, **Fig. 3**), and therefore it is possible to talk about the possible impact of air pollution on urban ecosystems, including lichen diversity. This is confirmed by the absence of bushy lichen species, which are most sensitive to air pollution.

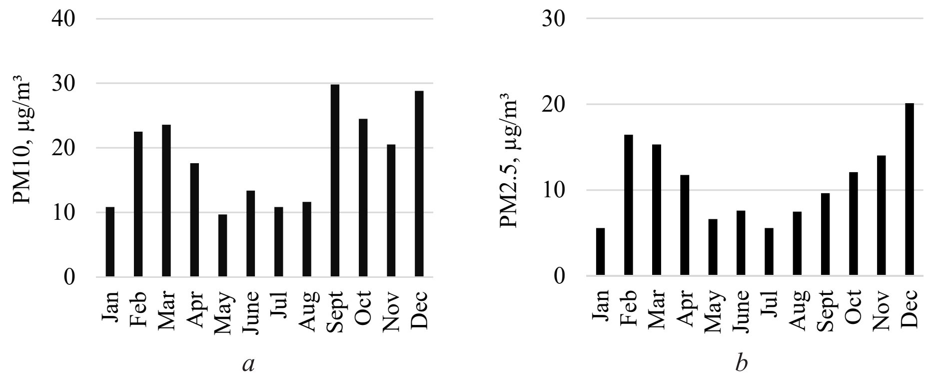

Fig. 3. Monthly dynamics of particulate matter concentrations according to the automated monitoring station in 2020: *a* – PM10, *b* – PM 2.5

4. Discussion

Parks-monuments of landscape art are artificially created objects of the nature reserve fund, unlike biosphere and nature reserves, national parks and other natural areas. Within large industrial cities, such sites are important environmental and recreational centers.

Given the high anthropogenic load on such areas, as green spaces perform sanitary and hygienic functions, primarily retaining particulate matter (PM), a relatively impoverished taxonomic diversity of lichen biota is expected. This correlates with studies of the diversity of epiphytic lichens in recreational areas of Zaporizhzhia (also a large industrial city located in the steppe zone of Ukraine) [22], where only 5 species were recorded. In our opinion, studies of the taxonomic diversity of the lichens of settlements located within the Forest-Steppe and Polissya are irrelevant for comparison, since climatic conditions (especially precipitation) differ significantly from those of the Steppe.

As a result of studies [11, 21] conducted on the territory of the plain part of Ukraine, a list of lichens with varying degrees of sensitivity to anthropogenic factors and promising for use as indicators is given: the most sensitive to atmospheric pollution are fruticose lichens of the genus Ramalina (*R. fraxinea*, *R. farinacea*, *R. lacera*, *R. dilacerata*) and the species *Evernia prunastri*, *E. mesomorpha*, *Pseudevernia*. The foliose lichens *Parmelia sulcata*, *Hypogymnia physoides*, as well as species of the Parmeliaceae family (*Pleurosticta acetabulum*, *Parmelina tiliaceae*, *Melanohalea exasperata*, *M. glabratula*) are moderately sensitive. The most resistant to acid pollution are *Scoliciosporum chlorococcum* and *Straminella conizaeoides*, and to dust pollution – *Xanthoria parietina*, *Polycauliona polycarpa*, *Physcia stellaris*, *Ph. adscendens*, *Ph. tenella*, *Phaeophyscia orbicularis*. It is worth noting that studies of the plains of Ukraine were concentrated in the following regions: Kirovohrad [23], Volyn [24], Rivne [24], Ternopil [24], and Kyiv [25, 26]. Dnipropetrovsk region has been not covered by these studies. It is also worth noting that the above regions (except for Kirovohrad region) are located in the forest-steppe zone, zones of mixed and broadleaf forests, and Dnipropetrovsk region is located in the steppe zone of Ukraine. The climate of the steppe zone is characterized by higher annual amplitudes of air temperature and lower precipitation, which significantly affects the diversity of lichen biota. The above indicates the relevance of research on lichen diversity in the Steppe Prydniprovia.

The work on identifying the taxonomic diversity of lichens in settlements with different degrees of anthropogenic load in the Steppe Prydniprovia has just begun. Let's consider it expedient to start the study with the objects of the nature reserve fund and green areas within settlements. After all, they are the centers of biodiversity in urban ecosystems [27]. Studies of the lichen biota of streets and areas directly adjacent to industrial facilities deserve special attention.

In our opinion, the study of the taxonomic diversity of the lichen biota of large industrial cities and other settlements is a promising area of research in terms of lichen indication. After all, in this case, lichen diversity is an integral indicator, and the results obtained are quite clear.

5. Conclusions

As a result of the research, 10 species of lichens from 6 families were recorded.

It is shown that the highest species diversity is characterized by the family Parmeliaceae (3 species), the families Teloschistaceae and Physciaceae are represented by two species each, the families Carbonicolaceae, Lecanoraceae, Lecanoromycetidae are represented by 1 species each.

It was recorded that 6 species are crustose, 4 are foliose, while fruticose species, which are most sensitive to air pollution, were not found.

Lichens have been recorded on the bark of living (24 species of trees and shrubs) and dead trees (2 species of trees), processed wood (carved sculptures, fences, parts of the equipment of adventure parks for children, etc.), concrete structures (slabs, curbs, poles), metal structures (reinforcement of concrete slabs, metal poles).

The largest number of lichen species was recorded on concrete substrates (8 species) and on the bark of *Acer negundo* (5 species). The smallest number of species (1 species each) was recorded on the bark of *Rhus typhina*, *Buxus sempervirens*, *Celtis occidentalis*, *Juniperus virginiana*, *Pinus nigra subsp. pallasiana*, *Rosa canina*, dead black poplar, and metal structures.

The greatest variety of substrates was inhabited by *Physcia adscendens* (27 substrates) and *Xanthoria parietina* (18 substrates). The smallest number of substrates (1 species) was inhabited by *Calogaya saxicola*, *Flavoparmelia caperata*, *Scythioria phlogina* and *Lecanora chlarotera*.

Currently, the data on lichen diversity in the protected areas of the city of Dnipro (Ukraine) is new. Let's also believe that another important result is that in large industrial cities, where, in addition to intensive traffic, there is a large number of stationary sources, there is a need to develop a specific plan for surveying tree stands and other substrates of protected areas and green zones, taking into account the types of substrates on which lichens are not found, as well as their number, side of the world, projective coverage, species composition of lichen communities recorded on one substrate, frequency of recording of different communities, etc.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

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Data availability

Data will be made available on reasonable request.

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