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ORIGINAL RESEARCH

Problems and challenges of lichen inventory in a changing environment: The case of the "Mszar" and "Redykajny" reserves in Olsztyn

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Abstract

The paper presents the state of knowledge of the lichen biota of the "Mszar" and "Redykajny" nature reserves, located in the "Las Miejski" urban forest complex in Olsztyn (north-eastern Poland). The results of the inventory conducted in 2024 are described, which are compared with published data collected in 1999–2001. So far, a total of 118 lichenized and three non-lichenized fungi have been identified in this area. Recent studies did not confirm the occurrence of 18 species, but at the same time showed 32 species new to the study area. The article discusses possible causes of changes in the species composition of the lichen biota over almost 25 years and the effectiveness of various methods of collecting data in the field. The results prove that both reserves are still important refuges of forest lichen biodiversity on a scale larger than just the area of Olsztyn's urban forests.

Keywords
lichenized fungi; species diversity; protected area; Poland

1. Introduction

Lichens are an important component of forest communities, constituting a significant part of their biodiversity (Ellis, 2012; Faliński & Mułenko, 1996; Sillet & Antoine, 2004). The most characteristic group of forest lichens are epiphytes, which exclusively, or at least primarily, inhabit the vast space created by trunks and crowns of living trees (Cieśliński et al., 1996; Ellis, 2012). Many lichen species also inhabit dead wood, as facultative or obligate epixylites (Chlebicki et al., 1996; Gutowski et al., 2023). The occurrence of lichen species and the diversity of the communities they create depend on many factors, the most important of which are the presence of suitable substrates and microhabitats (Cieśliński et al., 1996; Sillet & Antoine, 2004) and the specific forest microclimate (Gauslaa, 2014; Phinney et al., 2018). It is known that natural forest communities, usually with a mixed tree species composition and diverse age structure (Peterken, 1996), contain a much larger number of species than commercial forests, which are poorer in microhabitats and substrates (Bergamini et al., 2005; Boch et al., 2013; Hämäläinen et al., 2023; Tripp et al., 2019). Many lichen species have become dependent on these specific conditions and do not occur in managed forests (Boggess et al., 2024; Scheidegger & Stofer, 2015). Most of them are sensitive to changes in environmental conditions (Czerepko et al., 2021), which has been used in forest bioindication (Frati & Brunialti, 2023; Miller et al., 2020). Assessment of lichen diversity can also provide reliable information on processes occurring both locally and globally. Many natural and anthropogenic substances are transported over long distances from emission sources and are spread mainly by wet and dry deposition (Frati & Brunialti, 2023). Lichens have long been used in bioindication and monitoring of transboundary atmospheric pollution (Nash & Gries, 1991; Nimis et al., 2002) and, more recently, global warming (Aptroot et al., 2021; Stanton et al., 2023; Wrobleski et al., 2023). Changes in the species composition of the lichen biota can also inform about potential threats to human health (Cislaghi & Nimis, 1997; Frati & Brunialti, 2023; Loppi, 2014), therefore it is important to initiate, continue and expand research on lichen diversity in areas located near human settlements. Due to the close proximity to the city and the high risk of exposure to many harmful environmental factors, monitoring the condition of urban forests seems particularly justified.

The aim of the study was to investigate the species diversity of lichen biota in the "Mszar" and "Redykajny" nature reserves in Olsztyn (north-eastern Poland) and to determine possible changes in its composition over the past 25 years.

Figure 1 Swamp birch forest *Betuletum pubescentis*, "Mszar" nature reserve, locality no. 4 (D. Kubiak).

2. Materials and methods

2.1. Study site

The "Mszar" and "Redykajny" nature reserves are located within the administrative borders of the city of Olsztyn (over 170,000 inhabitants) in the large (over 1,400 ha) "Las Miejski" woodland complex (Kubiak, 2008). According to the current geographical division of Poland (Solon et al., 2018), both reserves are located in the Olsztyn Lakeland mesoregion. According to the national ATPOL system of grid squares (Verey, 2017), adapted for the plotting of lichen stands (Cieśliński & Fałtynowicz, 1993), both reserves are located in square Be42. The "Redykajny" reserve was established in 1949 over an area of 9.96 ha, while the "Mszar" reserve was established in 1953 over an area of 5.24 ha. The aim of conservation efforts in both reserves is the preservation of raised bogs and boggy forest and shrub communities (CRFOP, 2024; Figure 1, Figure 2, Table 1). Although both areas obtained the status of protected areas in 1907, the first studies of lichen biota were conducted in 1999–2001 (Kubiak, 2008).

2.2. Field research

Field data were collected in 2024. Unlike the previous inventory (cf. Kubiak, 2008), information on the occurrence of species and the substrates they inhabited was linked to specific field points. These points were designated for all types of communities in the study area. The number of points in a specific type of community corresponded to its share in the total area of the reserve. Data were collected around a previously designated point at a distance of 10 m (over 300 m^2) on all substrates inhabited by these organisms. At each point, geographical coordinates (WGS 1984) were recorded, and the type of local community was determined. The list and general characteristics of the research sites are presented in Table 1. In total, a field study was carried out at 23 sites, including seven within the "Mszar" reserve and 16 within the "Redykajny" reserve. Species that were identified in the field were recorded without collecting specimens. For the remaining taxa, small fragments of thallus were collected for further morphological, anatomical, and chemical studies.

2.3. Species identification

Standard spot tests and chromatographic analysis (TLC, solvent C) were used to identify the collected specimens (Orange et al., 2001). The nomenclature of the lichen species follows Fałtynowicz et al. (2024). The categories of lichen threat in Poland are given according to Cieśliński et al. (2006), and the indicator species of lowland primeval forests are given according to Czyżewska and Cieśliński (2003). The collected herbarium material was deposited in the lichen herbarium at the Department of Microbiology and Mycology of the University of Warmia Masuria in Olsztyn (OLTC-L). As part of this part of the study, taxonomic re-identification of specimens collected in 1999–2001 and deposited in OLTC-L was also performed.

3. Results and discussion

3.1. General characteristics of the lichen biota

As a result of research conducted in 2024, 100 lichenized and three non-lichenized fungi were identified, including 71 in the "Mszar" reserve and 90 in the "Redykajny" reserve (all non-lichenized fungi were recorded in the "Redykajny" reserve).

Figure 2 Boggy pine forest *Vaccinio uliginosi-Pinetum*, “Redykajny” nature reserve, locality no. 2 (D. Kubiak).

After comparing these results with data from 1999–2001, the total number of species recorded in the study area increased to 121 (Table 2). The latest studies resulted in an increase of this number by 32 species, of which 18 are new to the “Mszar” reserve, and 26 are new to the “Redykajny” reserve. However, the study did not confirm the occurrence of 18 previously recorded species. It should be noted that two species were given in the report of the first inventory (Kubiak, 2008), i.e., *Bacidina assulata* (Körb. S. Ekman and *Placynthiella uliginosa* (Schrad.) Coppins & P. James, are not included in Table 2. The specimen of the first species deposited in OLTC-L and revised in 2024 belongs to *Bacidia arceutina* (Ach.) Arnold) and the second to *P. dasaea* (Stirt.) Tønsberg.

The list of species recorded in both reserves includes 29 threatened and near threatened species which are included in the national Red List, and representing the following categories: 1 – Critically Endangered (*Chaenotheca chlorella*), 8 – Endangered (*Anaptychia ciliaris*, *Bacidia arceutina, Calicium trabinellum*, *Cetraria sepincola*, *Chaenotheca brachypoda*, *Ch. stemonea*, *Toniniopsis separabilis*, *Usnea subfloridana*), 10 – Vulnerable (*Bacidia rubella*, *Biatora efflorescens*, *Bryoria fuscescens*, *Chaenotheca xyloxena*, *Nephromopsis chlorophylla*, *Ochrolechia bahusiensis*, *Parmelia submontana*, *Peltigera praetextata, Ramalina farinacea*, *Usnea hirta*), and 10 – Near Threatened (*Chaenotheca furfuracea*, *Ch. trichialis*, *Evernia prunastri*, *Graphis scripta*, *Hypogymnia tubulosa*, *Lecanora sarcopisoides*, *Lichenomphalia umbellifera*, *Micarea melaena*, *Pertusaria coccodes*, *Vulpicida pinastri*). The list also includes 13 species legally protected at the national level. Of this group, five species are under strict protection (*A. ciliaris*, *C. sepincola*, *P. submontana*, *P. praetextata*, *Usnea subfloridana*) and eight are under partial protection (*B. fuscescens*, *Cladonia arbuscula*, *H. tubulosa*, *Melanelixia subaurifera*, *N. chlorophylla*, *Ramalina farinacea*, *Usnea hirta*, *V. pinastri*). Four of the above-mentioned species have the status of lowland primeval forest indicators in Poland: *C. trabinellum*, *Ch. brachypoda*, *Ch. chlorella*, and *M. melaena*.

3.2. Lichen species new to the study area

The significant increase in the number of species between the two study periods raises the question of the cause of this change. The most obvious explanation is that the newly discovered species were not previously known and were described as new to science within the last few years (Czarnota & Guzow-Krzemińska, 2010; Guzow-Krzemińska et al., 2016, 2017). However, these species are not numerous (*Lecanora stanislai, Micarea byssacea, M. soralifera*), and there is a predominance of well-known taxa (both rare and even common) with an established taxonomic position and quite well-understood ecology (e.g. *Chaenotheca chrysocephala*, *Graphis scripta*, *H. tubulosa*, *Lecanora argentata*, *Lepra albescens*, *Physcia adscendens, Polycauliona polycarpa*). It may seem that due to the sessile and perennial lifestyle and lack of seasonality in this group of organisms – apart from a few exceptions (Poelt & Vězda, 1990), identification of the majority of lichen species in the field should be simple, compared to some plants or other groups of fungi (von Hirschheydt et al., 2024). Nonetheless, in practice, the number of identified species typically differs from the actual number, and these differences are not limited only to the most inconspicuous, poorly known, or as yet not described taxa. As many field experiments have shown (Vondrák et al., 2016, 2018; von Hirschheydt et al., 2024), the assessment of the biodiversity of lichens may be a challenge even for expert taxonomists. Variables influencing the inventory result can be considered from the perspective of the used research method and environmental heterogeneity. In terms of the process of the inventory (excluding the previ-

Table 1 Description and geographical coordinates of the study sites in the "Mszar" and "Redykajny" reserves (Poland).

Study sites (no.)	Geographical coordinates (latitude/longitude)	Description (present and potential plant community)
		Mszar
1	53°47′15.8″N, 20°27′51.9″E	Pine-birch swamp forest *Thelypteridi-Betuletum pubescentis*
2	53°47′17.4″N, 20°27′55.7″E	Alder swamp forest *Ribeso nigri-Alnetum*
3	53°47′17.5″N, 20°27′53.5″E	Swamp birch forest *Betuletum pubescentis*
4	53°47′19.2″N, 20°27′54.6″E	Swamp birch forest *Betuletum pubescentis* (Figure 1)
5	53°47′21.6″N, 20°27′54.0″E	Edge of the fresh pine forest *Peucedano-Pinetum* (potential vegetation: boreal spruce forest *Sphagno girgensohnii-Piceetum*) and raised-bog community *Ledo-Sphagnetum magellanici*
6	53°47′20.8″N, 20°27′56.9″E	Mixed old-growth spruce-birch forest (potential vegetation: boreal spruce forest *Sphagno girgensohnii-Piceetum*)
7	53°47′21.1″N, 20°27′51.2″E	Fresh pine forest *Peucedano-Pinetum* (potential vegetation: boreal spruce forest *Sphagno girgensohnii-Piceetum*)
		Redykajny
1	53°47′45.6″N, 20°27′10.7″E	Edge of the mixed forest (potential vegetation: continental mixed forest *Querco roboris-Pinetum*) and wet meadow
2	53°47′47.6″N, 20°27′11.4″E	Boggy pine forest *Vaccinio uliginosi-Pinetum* (Figure 2)
3	53°47′49.0″N, 20°27′10.0″E	Boggy pine forest *Vaccinio uliginosi-Pinetum*
4	53°47′50.8″N, 20°27′06.8″E	Alder swamp forest *Ribeso nigri-Alnetum*
5	53°47′44.1″N, 20°27′10.8″E	Group of old deciduous trees on the edge of a mixed forest (potential vegetation: continental mixed forest *Querco roboris-Pinetum*) and wet meadow
6	53°47′44.2″N, 20°27′17.1″E	Spruce forest (potential vegetation: continental mixed forest *Querco roboris-Pinetum*)
7	53°47′42.7″N, 20°27′07.9″E	Multi-species group of trees on the edge of the reserve, by the mid-forest road
8	53°47′45.5″N, 20°27′05.7″E	Old alders on the edge of a mixed forest, next to a drainage ditch
9	53°47′46.9″N, 20°27′07.7″E	Fresh pine forest *Peucedano-Pinetum*
10	53°47′47.4″N, 20°27′07.0″E	Boggy pine forest *Vaccinio uliginosi-Pinetum*
11	53°47′47.9″N, 20°27′08.8″E	Edge of boggy pine forest *Vaccinio uliginosi-Pinetum* and raised-bog community *Ledo-Sphagnetum magellanici*
12	53°47′47.5″N, 20°27′03.7″E	Mixed alder-birch forest (potential vegetation: swamp birch forest *Betuletum pubescentis*)
13	53°47′45.0″N, 20°27′02.2″E	Boreal spruce forest *Sphagno girgensohnii-Piceetum* (old-growth stand)
14	53°47′47.5″N, 20°26′58.2″E	Alder forest (potential vegetation: alder turf forest *Sphagno squarrosi-Alnetum*)
15	53°47′49.7″N, 20°26′56.4″E	Alder forest (potential vegetation: alder turf forest *Sphagno squarrosi-Alnetum*)
16	53°47′49.9″N, 20°26′52.9″E	Old elm tree on the edge of the reserve, near the forest path (potential vegetation: subboreal humid mixed forest *Querco-Piceetum*)

ously mentioned knowledge and experience of the members of the research team), the number of species found in a given area positively correlates with the number of researchers and the amount of time spent in the field (Vondrák et al., 2016). Apart from the random (probabilistic) approach to data collection, which is particularly suitable for larger areas with a less diverse environment, in the practice of lichenological inventories of smaller areas, two methods of recording species can be distinguished. The first involves the relatively uniform penetration of the entire area (route or cartographic method; see Faliński, 1990), while in the second, the researchers focus their attention on places that are potentially important for the diversity of lichens, so-called biodiversity hotspots (Peterson & McCune, 2003; Vondrák et al., 2016, 2022). Both methods have their advantages and disadvantages, but it would seem that in order to identify the largest number of species, in particular microlichens, the second approach is more efficient (Hofmeister et al., 2022; Vondrák et al., 2018). The optimal solution would be a combination of both methods (Ravera & Brunialti, 2013), but such a differentiated approach would hinder the analysis of the data obtained and the drawing of conclusions on their basis while also limiting the repeatability of the study. In assessing the results presented in this paper in terms of the applied research methodology, it should be noticed that a different method of collecting data was applied in the two different study periods. In the first period, the study was conducted using the route (topographic) method (see Faliński, 1990; Kubiak, 2008). It is difficult not to conclude that when using this method, the researcher has a tendency to avoid areas that

Table 2 List of species recorded in the "Mszar" and "Redykajny" reserves in 1999–2001 and 2024. Numbers in the columns 4–5 correspond to the number of study sites in Table 1. Newly recorded species are in bold.

Species	**1999–2001**		**2024**	
	Mszar	**Redykajny**	**Mszar**	**Redykajny**
1	*2*	*3*	*4*	*5*
Absconditella lignicola Vězda & Pišút	—	+	5	3,12,13
Amandinea punctata (Hoffm.) Coppins & Scheid.	+	—	—	1
Anaptychia ciliaris (L.) Körb.	—	+	—	—
Anisomeridium polypori (Ellis & Everh.) M.E. Barr	—	—	2	7,16
Bacidia arceutina (Ach.) Arnold	—	—	1	7,13
Bacidia fraxinea Lönnr.	—	+	—	7
Bacidia rubella (Hoffm.) A. Massal.	—	+	—	7
Bacidina modesta (Zwackh ex Vain.) S. Ekman	—	+	1–3	14
Biatora efflorescens (Hedl.) Räsänen	—	+	2	14
Bryoria fuscescens (Gyeln.) Brodo & D. Hawksw.	—	—	3	—
Buellia griseovirens (Turner & Borrer ex Sm.) Almb.	+	+	2–5	3,4,7,10,14
***Calicium trabinellum* (Ach.) Ach.**	+	—	**4**	—
Candelariella efflorescens R.C. Harris & W.R. Buck	—	—	4	4
Carbonicola anthracophila (Nyl.) Bendiksby & Timdal	+	—	—	9
Catillaria nigroclavata (Nyl.) J. Steiner	—	—	1	—
Cetraria sepincola (Ehrh.) Ach.	+	—	—	—
Chaenotheca brachypoda (Ach.) Tibell	—	—	—	7,13
Chaenotheca chlorella (Ach.) Müll.Arg.	—	—	—	9
Chaenotheca chrysocephala (Ach.) Th.Fr.	—	—	—	5,8,10
Chaenotheca ferruginea (Turner ex Sm.) Mig.	+	+	1,2,4–7	4,5,7,9–11,14,15
Chaenotheca furfuracea (L.) Tibell	—	+	—	4,13
Chaenotheca stemonea (Ach.) Müll.Arg.	+	+	1,2,6,7	7,8
Chaenotheca trichialis (Ach.) Th.Fr.	+	—	2,4,6,7	4,5,8,14,15
Chaenotheca xyloxena Nádv.	—	+	4,7	9,10,13
#*Chaenothecopsis pusiola* (Ach.) Vain.	—	+	—	9
Cladonia arbuscula (Wallr.) Flot. em. Ruoss subsp. arbuscula	—	+	—	—
Cladonia cenotea (Ach.) Schaer.	+	—	4,5,7	3,10
Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.	—	+	—	2,4,12
Cladonia coniocraea (Flörke) Spreng.	+	+	1–7	1–5,7–15
Cladonia digitata (L.) Hoffm.	+	+	2,4,5,7	1–5,9–11,14
Cladonia fimbriata (L.) Fr.	+	+	2,4,5,7	1–3,7,9,10,12,13,15
Cladonia floerkeana (Fr.) Flörke	+	—	7	10,11
Cladonia glauca Flörke	+	—	—	9
Cladonia grayi G. Merr. ex Sandst.	—	+	—	12
Cladonia macilenta Hoffm.	+	+	1,4,5,7	2,3,5,10,15
Cliostomum leprosum (Räsänen) Holien & Tønsberg	—	—	—	9
Coenogonium pineti (Ach.) Lücking & Lumbsch	—	+	1–7	1–9,11–16
Diarthonis spadicea (Leight.) Frisch, Ertz, Coppins & P.F. Cannon	—	—	2,4	4,5,7,8,13–16
Evernia prunastri (L.) Ach.	+	+	1–3,5,7	5,6,11
Fuscidea arboricola Coppins & Tønsberg	—	+	2,4	4,15
Fuscidea pusilla Tønsberg	—	+	4,5	4,7,9,11,12,15
Graphis scripta (L.) Ach.	—	—	1	8,14
Hypocenomyce scalaris (Ach.) M. Choisy	+	+	1,4,5,7	2,3,5,7–9,11,14,15

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Table 2 *Continued.*

Species	1999–2001		2024	
	Mszar	Redykajny	Mszar	Redykajny
Hypogymnia physodes (L.) Nyl.	+	+	1–5,7	2–7,9–15
Hypogymnia tubulosa (Schaer.) Hav.	—	—	2–4,7	6,9–11,13
Imshaugia aleurites (Ach.) S.L.F. Meyer	—	+	—	3,5,9,10
Lecania cyrtella (Ach.) Th.Fr.	—	+	—	11
Lecania cfr *cyrtellina* (Nyl.) Sandst.	—	+	—	—
Lecania naegelii (Hepp) Diederich & van den Boom	—	—	2	—
Lecanora argentata (Ach.) Malme	—	+	—	—
Lecanora carpinea (L.) Vain.	—	+	—	—
Lecanora chlarotera Nyl.	—	+	—	7
Lecanora conizaeoides Nyl. ex Cromb.	+	+	1,3–5	3,5,10,11
Lecanora expallens Ach.	+	+	1,4,7	5,14,15
Lecanora pulicaris (Pers.) Ach.	+	+	1–4,7	3,4,6,9–12,14
Lecanora sarcopidoides (A. Massal.) Hedl.	—	—	4	—
Lecanora stanislai Guzow-Krzem., Łubek, Malíček & Kukwa	—	—	1,4,	12,14,15
Lecidea nylanderi (Anzi) Th.Fr.	—	+	4,	3,9–11
Lecidella elaeochroma (Ach.) M. Choisy	—	+	—	—
Lecidella subviridis Tønsberg	—	—	—	4,16
Lepra albescens (Huds.) Hafellner	—	—	—	14
Lepra amara (Ach.) Hafellner	—	+	—	5,8,14
Lepraria eburnea J.R. Laundon	—	+	—	4
Lepraria elobata Tønsberg	+	+	1–5,7	4,5,7,12–15
Lepraria finkii (B. de Lesd. ex Hue) R.C. Harris	—	+	—	5,7,8,13–16
Lepraria incana (L.) Ach.	+	+	1–7	1–5,7–9,11–16
Lepraria jackii Tønsberg	+	+	1–5,7	2–12,14
Lepraria vouauxii (Hue) R.C. Harris	—	—	—	4,7,12
Lichenomphalia umbellifera (L.) Redhead, Lutzoni, Moncalvo & Vilgalys	—	—	1	5,10,13
Melanelixia glabratula (Schaer.) O. Blanco et al.	+	+	1	7,14
Melanelixia subaurifera (Nyl.) O. Blanco et al.	—	—	2–4,7	7,10,11,14
Melanohalea exasperatula (Nyl.) O. Blanco et al.	—	+	7	5,11
Micarea botryoides (Nyl.) Coppins	—	—	1	—
Micarea byssacea (Th. Fr.) Czarnota, Guzow-Krzem. & Coppins	—	—	—	4,7
Micarea denigrata (Fr.) Hedl.	+	—	—	3,10,12
Micarea melaena (Nyl.) Hedl.	+	—	—	—
Micarea micrococca (Körb.) Coppins		—	1,4	9,11
Micarea misella (Nyl.) Hedl.	+	—	1,4,5	1,9,10,12
Micarea cfr. *nigella* Coppins	+	—	—	—
Micarea nitschkeana (J. Lahm ex Rabenh.) Harm.	—	+	—	—
Micarea soralifera Guzow-Krzemińska, Czarnota, Łubek & Kukwa	—	—	—	9,12
Micarea viridileprosa Coppins & van den Boom	—	—	7	12
#*Microcalicium ahlneri* Tibell	—	—	—	9
Nephromopsis chlorophylla (Willd.) Divakar, Crespo & Lumbsch	—	+	2–4	—
Ochrolechia bahusiensis H. Magn.	—	+	2	4,7,8,12,14
Ochrolechia microstictoides Räsänen	—	+	—	—
Palicella filamentosa (Stirt.) Rodr. Flakus & Printzen	—	+	4	10,11,12

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Table 2 *Continued.*

Species	1999–2001		2024	
	Mszar	Redykajny	Mszar	Redykajny
Parmelia submontana Nádv. ex Hale	—	+	—	—
Parmelia sulcata Taylor	+	+	1–5,7	1,3–7,9–11,14,15
Parmeliopsis ambigua (Wulfen) Nyl.	+	+	1,3,4,7	3,5,9,10,14
Peltigera praetextata (Flörke) Zopf	—	—	—	7
Pertusaria coccodes (Ach.) Nyl.	—	+	—	—
Phaeophyscia orbicularis (Neck.) Moberg	—	+	—	7
Phlyctis argena (Ach.) Flot.	—	+	2–4	4,7,12–15
Physcia adscendens (Fr.) H. Olivier	—	—	1,2	14
Physcia stellaris (L.) Nyl. subsp. stellaris	—	+	—	—
Physcia tenella (Scop.) DC.	—	+	1,2,4,7	2,4,10,11,14
Physconia enteroxantha (Nyl.) Poelt	—	+	—	—
Placynthiella dasaea (Stirt.) Tønsberg	+	+	1,2,4,5,7	2–5,10,12,13
Placynthiella icmalea (Ach.) Coppins & P. James	+	+	4,7	1,3–5,10,12
Platismatia glauca (L.) W.L. Culb. & C.F. Culb.	+	+	1–3	3,5,6,10,11,14
Polycauliona polycarpa (Hoffm.) Frödén, Arup & Søchting	—	—	—	14
Porina aenea (Wallr.) Zahlbr.	—	—	1,7	14
Pseudevernia furfuracea (L.) Zopf	+	+	1,3–5,7	3,9–11,14
Pycnora sorophora (Vain.) Hafellner	+	+	4,7	3,5,9–12
Ramalina farinacea (L.) Ach.	+	+	—	5,7
Ropalospora viridis (Tønsberg) Tønsberg	—	+	2,4	2,4,7,9,11–15
Scoliciosporum chlorococcum (Graeve ex Stenh.) Vězda	+	+	—	—
Scoliciosporum sarothamni (Vain.) Vězda	—	+	2,3	9,11
#*Stenocybe pullatula* (Ach.) Stein	—	+	—	4,14
Thelidium minutulum Körb.	—	+	—	—
Toniniopsis separabilis (Nyl.) Gerasimova & A. Beck	—	—	—	7
Trapeliopsis flexuosa (Fr.) Coppins & P. James	+	+	4,5,7	3,5,10
Trapeliopsis gelatinosa (Flörke) Coppins & P. James	—	—	4	—
Trapeliopsis granulosa (Hoffm.) Lumbsch	+	+	1,4,5,7	1,3,10,12,13
Usnea hirta (L.) Weber ex F.H. Wigg.	—	+	3	10,11
Usnea subfloridana Stirt.	+	+	4	—
Vulpicida pinastri (Scop.) J.-E. Mattson & M.J. Lai	+	—	4	3,10,12
Violella fucata (Stirt.) T. Sprib.	—	+	1,4,5,7	1–5,7,9–12,14
Xanthoria parietina (L.) Th.Fr.	—	+	1	—
Xylopsora caradocensis (Leight. ex Nyl.) Bendiksby & Timdal	—	+	—	—
A total	**42**	**76**	**71**	**93**
	89		**103**	
	121			

Non-lichenized fungi.

are difficult to access (as well as those that are permanently or seasonally inaccessible) or those that are assumed to be uninteresting in lichenological terms. This may lead to the omission of certain highly specialised species (Vondrák et al., 2024). In the case of studies conducted using the point method, this forces the researcher to conduct a systematic search of microhabitats and substrates, regardless of the preliminary assessment of their interest in lichenological terms. To minimize the subjectivity of the selection of research sites, it is worthwhile to respect the principle of determining these in each of the identified types of habitats, including in their ecotonic zones, as was done during the second inventory in this study. It seems that the reason that many new species were identified, in particular those that belong to the so-called microlichens, at least in part, was due to the different procedures for data collection. Perhaps the number of their locations and the number of individuals increased during the analyzed period, which made their identification easier in 2024. It seems that the appearance of some of the newly recorded species can be associated with an increase in the amount of deadwood among the spruce undergrowth. Quite characteristic communities of epiphytic lichens formed on the dead spruce branches composed both of lichens that had not been recorded previously (*H. tubulosa*, *B. fuscescens, M. subaurifera*) and species that were known from the previous inventory, but it would seem, had increased in numbers (*E. prunastri*, *Platismatia glauca*, *Pseudevernia furfuracea*, *U. hirta*). Numerous studies show that the population dynamics of organisms such as lichens are closely linked with the dynamics of forest substrates, either continuously linked or linked at certain stages of their individual development (Scheidegger & Werth, 2009). Such a role is played by deadwood in various forms, which for many epiphytes is a substitute substrate and a centre for dispersion of diasporas into the environment (Tanona & Czarnota, 2023). A separate category of dead wood is dead fallen tree trunks. Depending on the type of tree and local microclimatic conditions, this substrate may be colonized by specialized epixylites, which are different from those associated with deadwood in exposed places (especially in the case of dead, standing trees), which are present, for example, in the boggy pine forest community. As a result of the second inventory, several new species for the area were identified on the dead and fallen trunks of deciduous trees in shady and damp localities: *Ch. brachypoda*, *L. umbellifera, P. praetextata* and *Trapeliopsis gelatinosa*. The most significant risk for the forest lichen biota is the serious degradation or loss of habitat (Pykälä, 2019; Wolseley, 1995). In the case of the studied area, this type of threat was not observed, among other reasons, due to the habitat diversity of both reserves and their location within a large forest complex, which may act as a buffer against many potential threats. However, in both reserves, natural succession processes took place. Of particular importance are those that concern areas that are crucial for reasons of preservation – raised bogs and boggy pine forests. Despite the clear reduction in surface area of these communities, so far, significant changes in the species composition of lichens that are associated with them (mainly epiphytes of pine and epixylites associated with dead pine wood) have not been observed. It is worth stressing that the most recent study confirmed the presence in these communities of *C. trabinellum*, a species that is considered endangered (EN) in Poland. The species is not found in Olsztyn outside of the “Mszar” reserve (Kubiak, 2005) and is very rare in northern Poland (Cieśliński, 2003; Szczepańska et al., 2023). The assessment of environmental processes on the basis of individual species, especially ones that do not occur in large numbers, is of doubtful value. Its validity, however, increases in the case of a larger number of species, especially if these form a group with similar ecological requirements and functions performed in the ecosystem – the so-called functional traits (Ellis et al., 2021). As a result of the second inventory, in both reserves, a group of new species was identified, including epiphytic crustose lichens, which are considered characteristic of shady and damp deciduous forests (*Anisomeridium polypori*, *Diarthonis spadicea*, *G. scripta*, *Porina aenea*). These species undoubtedly came from the forest complex that surrounds both reserves, a complex that is dominated by stands of pine growing in relatively fertile habitats typical of oak-hornbeam forests (BDoL, 2024). This phenomenon can be interpreted as a subtle signal of changes in the structure of conifer stands, primarily those growing at the edges of both peatland basins, which is expressed by an increasing share of deciduous species (including beech). Interestingly, the species are linked by the presence of the same photobiont from the genus *Trentepohlia* Mart. Aptroot and van Herk (2007), based on studies conducted in the Netherlands, showed that lichens containing this type of photobiont are increasing their range and numbers as a result of the global warming climate. Although comparative studies from the periods 1987–1989 and 2014–2015 conducted in the Białowieża Forest (one of the best-preserved forest complexes in the European lowlands) did not confirm a similar phenomenon (Łubek et al., 2021), it is much more likely in urbanized areas, which has so far been confirmed in studies of lichens in cities in western and southern Europe (Aptroot & van Herk, 2007; Munzi et al., 2014). As can be seen from the examples provided, the group of species recorded as new for the area in 2024 includes lichens with diverse morphology, habitat preferences, and reactions to environmental changes. It is worth emphasizing that threatened species are among them: *B. fuscescens, Ch. brachypoda, Ch. chlorella, G. scripta, H. tubulosa, L. sarcopidoides, L. umbellifera, P. praetextata, T. separabilis*, and *T. gelatinosa*.

3.3. Extinct and/or unconfirmed species

It should be noted that due to the previously described problems with complete identification of species, caution should be exercised when defining species as locally extinct. Undoubtedly, some species have disappeared from the research area, such as *C. arbuscula*, *A. cilaris*, and *P. submontana*. The first species was found in the “Redykajny” reserve. A single, small thallus grew on a dead, strongly decomposed stump in a pine bog forest. Its extinction was probably caused by the natural succession of this substrate. The last two lichens were also recorded in the “Redykajny” reserve, where they grew on single, mature deciduous trees, *Acer platanoides* and *Populus tremula*. These trees had toppled, and as a result, the epiphytes inhabiting them died. These phorophytes are represented in minimal numbers in both reserves, creating a severe risk to the associated lichens. In the past, several familiar lichens were associated with the aforementioned phorophytes, which were not identified in 2024 (e.g., *Lecanora carpinea, Lecidella elaeochroma, Physcia stellaris, Phaeophyscia enteroxantha*). Among the rare and/or threatened lichens, the occurrence of only three species has not been confirmed: *C. sepincola*, *M. melaena*, and *P. coccodes*.

4. Conclusions

Knowledge of species and their distribution, especially in protected areas, is essential not only for scientific reasons but also for practical justification. It is crucial to undertake conservation measures and allow them to be adapted to the biology and ecology of individual species. However, it should be remembered that obtaining a complete list of lichen species in forests is very difficult, if not impossible. Therefore, it is important to use different data collection methods, allowing for obtaining a more complete list of species.

The conducted studies have shown that a relatively short period separating the two inventories is sufficient for changes in relatively well-preserved forest communities that are significant enough to be reflected in the species composition of lichens. This confirms the generally known good bioindicative properties of lichens but, at the same time, forces the need for constant monitoring of the diversity of these organisms.

The different ecological requirements of lichens and their varying sensitivity to environmental changes can pose a significant challenge for nature conservation services and often require different compromises in their actions. It is important to establish conservation priorities, which should focus on selected species – rare and/or threatened, with well-known biology and ecology. Since these are usually stenoecious species adapted to specific substrates and/or communities, the best solution is to protect their habitats.

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