Folia Forestalia Polonica, Series A – Forestry, 2024, Vol. 66 (1), 8–21

ORIGINAL ARTICLE

DOI: 10.2478/ffp-2024-0002

"Sosny Taborskie" nature reserve as a refuge for rare and threatened forest lichens

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Abstract

The article presents the results of a lichenological inventory carried out in the "Tabórz Pine" nature reserve, which protects a unique old-growth forest dominated by Scots pine and European beech. The aim of the research was to document the taxonomic and ecological diversity of the lichen biota in the reserve and, on this basis, determine the role and importance of this site as a refuge for stenoecious forest lichens. In an area of 95.32 ha, 118 species of lichens were found, including 43 species included in the Polish national Red List along with 17 species having the status of lowland old-growth forests in Poland. These values allow the reserve to be included in the group of important forest lichen refuges in north-eastern Poland. The obtained results also prove that mixing tree species with complementary ecological features can modify the functioning of the forest not only in terms of its economic features, but also its ecological role in shaping and protecting the species diversity of forest lichens.

Key words

lichenized fungi, old-growth forest, protected area, species list

Introduction

North-eastern Poland is characterized by a large diversity of natural forest communities (Polakowski 1971; Sokołowski 2006; Hołdyński 2010). This is due not only to a very diverse young glacial landscape and a relatively low degree of anthropogenic environmental transformation, but also to the location of this region in the range of important forest-forming species, including the Norway spruce *Picea abies* and the European beech *Fagus sylvatica* (Jutrzenka-Trzebiatowski 1999). As a result, local forest communities specific to this region were created. An example of this is the forest complex of the Tabórz Forests, where a unique ecotype of the Scots pine *Pinus sylvestris* (Borowiec 1961; Fabijanowski 1961) has developed in relatively fertile forest habitats. The high breeding and technical quality of the local pine has been known since the 16th century, but the term "Tabor pine" as a trade term dates back to the beginning of the 19th century. The popularity of the Tabor pine has resulted in a decrease in its share in the forest stands of western Masuria (Ostróda Forest). Therefore, since the 17th century, activities aimed at protecting local forests have been initiated (Dziekoński 1998). The

Received 5 October 2023 / Accepted 21 November 2023

oldest and most dense fragments of pine stands were protected in 1958, creating a nature reserve called "Sosny Taborskie", with a total area of 95 ha (CRFOP 2023).

Numerous studies have been carried out in the reserve, in particular on the phenotypic diversity and genotypic variability of the Scots pine (Przybylski 1972; Remlein et al. 2015; Lesiczka et al. 2017), as well as the dynamics of its growth and the structure of the stands it co-creates (Fabijanowski 1961; Dudzińska 2012). These studies were conducted primarily in the context of the technical quality of the pine wood (Jelonek et al. 2016; Wąsik et al. 2016, 2020; Misi et al. 2019). However, data on the biocenotic role of the Scots pine and its participation within the forest stands are very scarce (Dominik and Wojciechowska 1961; Piętka et al. 2019).

The aim of the presented research was to identify the taxonomic and ecological diversity of the lichen biota of the "Sosny Taborskie" reserve and to determine the supra-regional role of this forest complex as a refugium for rare and threatened species.

Material and methods

Study area

The "Sosny Taborskie" nature reserve is located in the northern part of the Olsztynek Plain mesoregion (Solon et al. 2018). The reserve includes forest sections no. 93 and 94, as well as part of sections no. 95 and 106 of the Miłomłyn Forest District (BDoL 2023) with a total area of 95.32 ha. The reserve was estab-

Figure 1. An example of the mixed forest stand dominating in the reserve (locality no. 8) – Scots pine (260 years old) with European beech (120 years old) (photo D. Kubiak)

lished to protect the local Scots pine ecotype and natural succession processes in the dominant deciduous forest habitat of the *Querco-Fagetea* class (CRFOP 2023). The age of the pine stands is currently 120–260 years. The share of pine (according to forest management data) is estimated at 46%. All forest stands in the reserve are generally multi-species. In addition to pine, they consist of common beech, pedunculate oak *Quercus robur*, hornbeam *Carpinus betulus,* and spruce, and occasionally also include Norway maple *Acer platanoides*, silver birch *Betula pendula*, small-leaved lime *Tilia cordata*, European ash *Fraxinus excelsior* and aspen *Populus tremula*. The lower layers of the forest are dominated by beech (Fig. 1), which is several dozen years younger than the pine (120–260 years). This species, together with the hornbeam, is the first to fill newly formed gaps in the tree stand. The reserve is located in a relatively compact forest complex of the Tabórz Forests, also called the Ostróda Forest or the Ostróda-Tabórz Forest (Zaręba 1981). This complex is a nodal area in the national ecological network ECONET (Liro 1995) and co-creates an ecological corridor connecting the European Natura 2000 network in northern Poland (Gerlée 2010; Geoserwis 2023). From the east it borders the Ostoja Napiwodzko-Ramucka SCI, and from the west it borders the Ostoja Iławska SCI (Geoserwis 2023).

Data collection and species indentification

Field research on lichen biota was carried out in the reserve in 2015. Two field data collection methods were used to increase the accuracy of the results. The basic method of data collection was detailed observations at circular research sites with an area of 0.05 ha. These localities, 16 in number (Fig. 2), were identified in all types of tree stands present in the reserve (according to the dominant tree species), i.e. pine-beech stands – with a majority (sites no.: 3, 6–8, 13–16) or a minority (4, 5, 9, 10) share of pine, oak stands (1, 2, 11) and a birch stand (12). The number of sites in a given type of forest community was representative of its share in the reserve. The route method (M; see Tab. 1) was used as a complementary method, focusing on habitats that could provide new information on the taxonomic or ecological diversity of the lichen biota (e.g. biocenotic trees, fallen trees or branches, dead wood). Lichen species were identified directly in the field (only in the case of taxonomically unproblematic specimens) or small specimens were collected for further detailed morphological and chemical studies in the laboratory. Chemical properties were analysed by standard thin layer chromatography (TLC) according to the method summarised by Orange et al. (2001). The nomenclature of taxa generally followed Fałtynowicz and Kossowska (2016), except for the species: *Bacidina mendax* (Czarnota and Guzow-Krzemińska 2018), *Lecania croatica* (Kotlov 2004), *Lecanora substerilis* (Malíček et. al. 2017), *Lecanora stanislai* (Guzow-Krzemińska et al. 2017), *Lepra* sp. (Hafellner and Türk 2016), and *Psoroglaena dictyospora* (Harada 2003). The collected material was deposited in the OLTC herbarium.

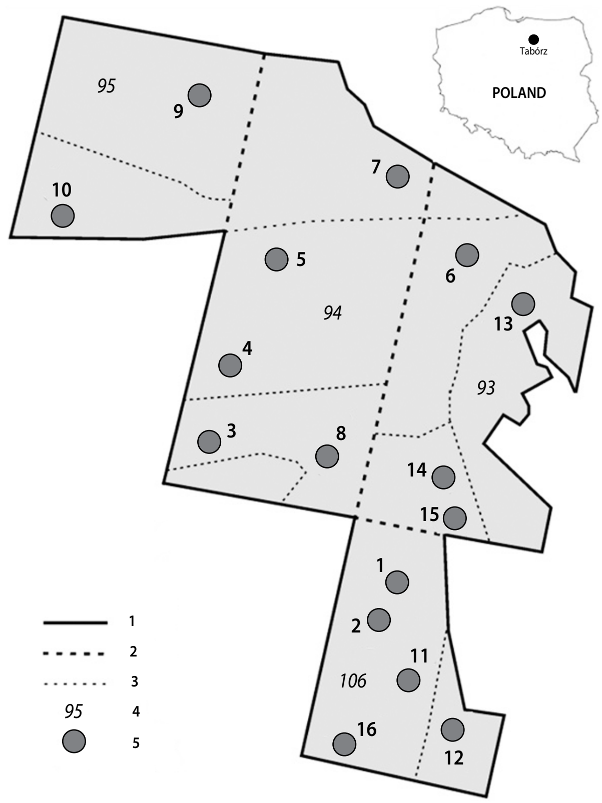

Figure 2. The location of the ”Sosny Taborskie” nature reserve in Poland and the distribution of the study localities in the reserve: 1 – border of the reserve, 2 – border of the forest section, 3 – border of the forest subsection, 4 – number of forest section, 5 – number of research locality

Results

As a result of the research, 118 species were distinguished in the reserve (Tab. 1), including 117 species of lichens (lichenized fungi) and one species of saprobic non-lichenized fungus (*Microcalicium disseminatum*). This number is probably slightly higher because the "*Micarea prasina*" group distinguished in this work (see Launis et al. 2019), represented in the world by 32 and in Poland by 12 species (Konoreva et al. 2020), probably includes several taxa in the reserve.

112 species of lichens were found in circular research plots, with the remaining six as a result of route research. Lichens were recorded on the bark of trees and shrubs (106 species, including 90 obligate species) and on dead wood (23 species, including 7 obligate species). Among epiphytes, the largest number of species (including exclusive ones) were found on the bark of oaks, totaling 68, and beeches, totaling 60 (Fig. 3). 17 species were recorded on pine, including two exclusive ones: *Xylospora caradocensis* and *Usnea subfloridana*.

Table 1. The list of lichen species recorded in the "Sosny Taborskie" nature reserve

No.	Species	Localities	Substrate	Red List categories
1	2	3	4	5
1	*Absconditella lignicola* Vězda & Pišut	1, 2, 15	wd	
2	*Acrocordia gemmata* (Ach.) A. Massal.	13, 14	Ap, Fe	
3	*Agonimia repleta* Czarnota & Coppins	1	Qr	
4	*Alyxoria varia* (Pers.) Ertz & Tehler	5, 9	Qr	NT
5	*Amandinea punctata* (Hoffm.) Coppins & Scheid.	1	Qr	
6	*Anisomeridium polypori* (M.B. Ellis & Everh.) M.E. Barr	2, 4, 5, 7–10, 13, 16	Ap, Fs, Qr, Tc	
7	*Arthonia arthonioides* (Ach.) A.L. Sm.	10	Qr	CR
8	*Arthonia didyma* Körb.	5, 8, 9	Fs	EN
9	*Arthonia mediella* Nyl.	9, 12, 14	Qr	VU
10	*Arthonia radiata* (Pers.) Ach.	1	Cb, Qr, Ug	
11	*Arthonia spadicea* Leight.	1–6, 8, 10–16	Cb, Fs, Ps, Qr, Tc	
12	*Arthonia vinosa* Leight.	8	Fs	NT
13	*Arthothelium ruanum* (A. Massal.) Körb.	6	Qr	NT
14	*Bacidia biatorina* (Körb.) Vain.	11	Qr	EN
15	*Bacidia rubella* (Hoffm.) A. Massal.	14	Ap	VU
16	*Bacidia subincompta* (Nyl.) Arnold	1, 2, 5–7, 13	Ap, Cb, Fe, Qr	EN
17	*Bacidina mendax* Czarnota & Guz.-Krzem.	M	Qr	
18	*Bacidina sulphurella* (Samp) M. Hauck & V. Wirth	1–11, 13	Ca, Cb, Fs, Qr, Tc, wd	
19	*Biatora efflorescens* (Hedl.) Räsänen	1–3, 5, 6, 8–11, 13–15	Ca, Cb, Fs, Qr, Tc	VU
20	*Biatora hemipolia* (Nyl.) S.Ekman & Printzen f. *pallida* Czarnota & Coppins	12	Qr	
21	*Biatora ocelliformis* (Nyl.) Arnold	8	Cb, Fs	VU
22	*Biatoridium monasteriense* J. Lahm	13	Fe	NT
23	*Buellia griseovirens* (Turner & Borrer ex Sm.) Almb.	1–6, 8–12	Cb, Fs	
24	*Calicium adspersum* Pers.	10	Qr	EN
25	*Calicium salicinum* Pers.	1–3, 8, 12	Qr	VU
26	*Calicium viride* Pers.	6, 12, 13	Qr	VU

1	2	3	4	5
27	*Candelariella efflorescens* R.C. Harris & W.R. Buck agg.	8, 9	Fs	
28	*Cetrelia olivetorum* (Nyl.) W.L. Culb. & C.F. Culb.	M	Qr	EN
29	*Chaenotheca chrysocephala* (Ach.) Th. Fr.	1–4, 12–14, 16	Qr, Pa	
30	*Chaenotheca ferruginea* (Turner ex Sm.) Mig.	1, 3, 4, 8, 10, 13–16	Pa, Ps, Qr	
31	*Chaenotheca furfuracea* (L.) Tibell	6, 8, 10, 12, 14, 16	Qr	NT
32	*Chaenotheca stemonea* (Ach.) Müll. Arg.	7, 13, 16	Ps, Qr	EN
33	*Chaenotheca trichialis* (Ach.) Th. Fr.	1, 2, 6, 9, 13	Fe, Ps, Qr, Tc, wd	NT
34	*Chenotheca xyloxena* Nádv.	M	wd	VU
35	*Chrysothrix candelaris* (L.) J.R. Laundon	1, 2, 4, 11, 13	Qr, Tc	CR
36	*Cladonia chlorophaea* (Flörke ex Sommerf.) Spreng.	2, 11, 12	Bp, Qr	
37	*Cladonia coniocraea* (Flörke) Spreng.	1–13, 15, 16	Cb, Bp, Fs, Pa, Ps, Qr, Tc, wd	
38	*Cladonia digitata* (L.) Hoffm.	3, 5, 7, 10, 12	Bp, Pa, Ps, wd	
39	*Cladonia fimbriata* (L.) Fr.	1, 12, 13, 16	Bp, Fs, Qr, Tc, wd	
40	*Cladonia macilenta* Hoffm.	1	wd	
41	*Cladonia parasitica* (Hoffm.) Hoffm.	4, 5	wd	EN
42	*Coenogonium pineti* (Schrad.) Lücking & Lumbsch	1–16	Bp, Cb, Fs, Pa, Ps, Qr, Tc, wd	
43	*Evernia prunastri* (L.) Ach.	1, 8, 9, 12	Fs, Qr, wd	NT
44	*Fellhanera gyrophorica* Sérus. & al.	1, 6, 8, 10–13, 15	Fs, Qr, Tc	LC
45	*Flavoparmelia caperata* (L.) Hale	M	Fs	EN
46	*Fuscidea arboricola* Coppins & Tønsberg	2, 3, 6, 8, 12, 14	Cb, Fs, Tc	
47	*Fuscidea pusilla* Tønsberg	12, 15	Bp, Pa	
48	*Graphis scripts* (L.) Ach.	1–13, 15, 16	Ca, Cb, Fs, Tc, Ug	NT
49	*Hypocenomyce scalaris* (Ach.) Choisy	1–3, 5–8, 12–14, 16	Bp, Fs, Pa, Ps, Qr, Tc	
50	*Hypogymnia physodes* (L.) Nyl.	1–4, 7–9, 11–13, 15, 16	Bp, Cb, Fs, Pa, Qr, wd	
51	*Hypogymnia tubulosa* (Schaer.) Hav.	3, 8	Fs Qr	NT
52	*Inoderma byssaceum* (Weigel) Gray	6	Qr	EN
53	*Lecania croatica* (Zahlbr.) Kotlov	1–3, 5, 6, 8, 12–14	Ca, Cb, Fs, Qr, Ug	
54	*Lecanora argentata* (Ach.) Malme	1, 2, 6–9	Ap, Cb, Fs, Qr	
55	*Lecanora carpinea* (L.) Vain.	5	Qr	
56	*Lecanora substerilis* Malíček & Vondrák	4, 6	Cb	
57	*Lecanora conizaeoides* Nyl.	M	Bp	
58	*Lecanora expallens* Ach.	1–16	Cb, Fe, Fs, Qr, Tc, Ug	
59	*Lecanora intumescens* (Rebent.) Rabenh.	11	Fs	EN
60	*Lecanora pulicaris* (Pers.) Ach.	8, 16	Fs, Qr	
61	*Lecanora saligna* (Schrad.) Zahlbr.	1	wd	
62	*Lecanora stanislai* Guzow-Krzem., Łubek, Malíček & Kukwa	1–4, 6, 9, 13	Ca, Qr, Tc	
63	*Lecanora thysanophora* R.C. Harris	1–9	Cb, Fs, Qr, Tc	
64	*Lecidea nylanderi* (Anzi) Th. Fr.	1	wd	
65	*Lecidella subviridis* Tønsberg	12	Fs	
66	*Lepra albescens* (Huds.) Hafellner	7	Ap	
67	*Lepra amara* (Ach.) Hafellner	1–13, 15, 16	Cb, Fs, Qr, Tc	

1	2	3	4	5
68	*Lepraria elobata* Tønsberg	1–16	Bp, Ca, Cb, Fs, Pa, Ps, Qr, Tc, wd	
69	*Lepraria finkii* (B. de Lesd. Ex Hue) R.C. Harrisyl.	1–11, 13–16	Ap, Ca, Cb, Fe, Fs, Qr Tc, Ug	
70	*Lepraria incana* (L.) Ach.	1–16	Ap, Bp, Ca, Cb, Fe, Fs, Pa, Ps, Qr, Tc, Ug, wd	
71	*Lepraria jackii* Tønsberg	1, 2, 4, 6, 10, 12, 13, 16	Bp, Pa, Ps, Qr, Tc, wd	
72	*Lepraria rigidula* (B. de Lesd.) Tønsberg	1–3, 9, 10, 12, 16	Bp, Cb, Fs, Tc	
73	*Lepraria vouauxii* (Hue) R.C. Harris	7, 14	Ap	
74	*Loxospora elatina* (Ach.) A. Massal.	4, 5	Fs	EN
75	*Melanelixia glabratula* (Lamy) O. Blanco & al.	116	Fs Cb Ps Tc Ca Ug	
76	*Melanohalea exasperatula* (Nyl.) O. Blanco & al.	M	Ca, Cb, Fs, Ps, Tc, Ug	
77	*Micarea misella* (Nyl.) Hedl.	1, 8	wd	
78	*Micarea prasina* grupa	1–16	Ps wd Tc Fs Qr Cb Pa Bp	
79	*Micarea tomentosa* Czarnota & Coppins	10, 16	Qr, wd	
80	*Micarea viridileprosa* Coppins & van den Boom	1	wd	
81	**Microcalicium disseminatum* (Ach.) Vain.	6, 13	Qr	
82	*Ochrolechia bahusiensis* H. Magn.	3–5, 8, 10–12, 14, 16	Fs, Qr	VU
83	*Ochrolechia microstictoides* Räsänen	2, 11	Bp, Fs	
84	*Opegrapha niveoatra* (Borrer) J.R. Laundon	2, 8–10, 14	Qr	VU
85	*Parmelia saxatilis* (L.) Ach.	2, 6, 8, 11, 12, 14, 16	Bp, Fs, Ps, Qr	
86	*Parmelia sulcata* Taylor	1–3, 5, 7–10, 13, 15, 16	Fs Qr Cb Ps wd Bp	
87	*Parmeliopsis ambigua* (Wulfen) Nyl.	1, 4, 8, 12, 16	Bp, Cb, Fs, Qr, Ps, wd	
88	*Pertusaria coccodes* (Ach.) Nyl.	5, 9, 12, 15	Fs, Qr	NT
89	*Pertusaria leioplaca* DC.	1	Cb	NT
90	*Pertusaria pupillaris* (Nyl.) Th. Fr.	8	Cb, Qr	NT
91	*Phaeophyscia endophoenicea* (Harm.) Moberg	3, 16	Fs	EN
92	*Phaeophyscia orbicularis* (Neck.) Moberg	16	Fs	
93	*Phlyctis argena* (Ach.) Flot.	1–10, 12–16	Ap, Ca, Cb, Fe, Fs, Qr, Tc, Ug	
94	*Physcia adscendens* (Fr.) H. Olivier	7	Fs	
95	*Physcia stellaris* (L.) Nyl.	8	Qr	
96	*Physcia tenella* (Scop.) DC.	1, 5–9, 16	Ap, Fs	
97	*Physconia enteroxantha* (Nyl.) Poelt	7, 10	Ap, Cb, Fs, Qr	
98	*Placynthiella dasaea* (Stirt.) Tønsberg	2, 5, 8–10, 13	Bp, Fs, wd	
99	*Placynthiella icmalea* (Ach.) Coppins & P. James	1–3, 8, 12	Bp, Fs, wd	
100	*Platismatia glauca* (L.) W.L. Culb. & C.F. Culb.	1, 3, 8, 9, 11, 12, 16	Bp, Fs, Qr, wd	
101	*Porina aenea* (Wallr.) Zahlbr.	1, 4–6, 8, 13–16	Cb, Fs, Qr, Tc, Ug	
102	*Pseudevernia furfuracea* (L.) Zopf	3, 8	Bp, Fs, Qr	
103	*Psoroglaena dictyospora* (Orange) H. Harada	2	Qr	
104	*Pyrenula nitida* (Weigel) Ach.	9	Fs	VU
105	*Pyrenula nitidella* (Flörke) Müll. Arg.	M	Fs	EN
106	*Ramalina farinacea* (L.) Ach.	1, 5, 8, 11, 12, 15	Bp, Fs, Qr	VU
107	*Ramalina pollinaria* (Westr.) Ach.	1, 10	Qr	VU
108	*Rinodina degeliana* Coppins	1, 8–10, 12, 13	Ca, Cb, Fs, Qr	

1	2	3	4	5
109	*Rinodina efflorescens* Malme	1, 2, 6–8, 12	Cb, Fs	
110	*Ropalospora viridis* (Tønsberg) Tønsberg	1–12, 14–16	Bp, Cb, Fs, Qr	
111	*Trapeliopsis flexuosa* (Fr.) Coppins & P. James	2, 8	Bp, wd	
112	*Trapeliopsis granulosa* (Hoffm.) Lumbsch	1	wd	
113	*Usnea dasopoda* (Ach.) Röhl.	3	Bp, Fs	VU
114	*Usnea subfloridana* Stirt.	1	Ps	EN
115	*Violella fucata* (Stirt.) T. Sprib.	2, 3, 8, 11, 16	Bp, Fs, Tc	
116	*Xanthoria parietina* (L.) Th. Fr.	8	Bp, Fs, Qr	
117	*Xylospora caradocensis* (Nyl.) Bendiksby & Timdal	13	Ps	
118	*Zwackhia viridis* (Ach.) Poetsch & Schied.	1, 5, 6, 8–11, 13–16	Cb, Fs, Qr, Tc	VU

Abbreviations: Ap – *Acer platanoides*, Bp – *Betula pendula*, Ca – *Corylus avellana*, Cb – *Carpinus betulus*, Fe – *Fraxinus excelsior*, Fs – *Fagus sylvatica*, Pa – *Picea abies*, Ps – *Pinus sylvestris*, Qr – *Quercus robur*, Tc – *Tilia cordata*, Ug – *Ulmus glabra*, wd – wood; *non-lichenized saprobic fungus; CR, EN, VU, LC, NT – red list categories according to Cieśliński et al. (2006); lichens – indicators of lowland old-growth forest in Poland (acc. to Czyżewska & Cieśliński 2003) are given in gray.

Eight species of lichens under species protection in Poland were found in the reserve, including three which are strictly protected (*Cetrelia olivetorum, Chrysothrix candelaris,* and *Usnea subfloridana*) and five which are partially protected (*Flavoparmelia caperata, Hypogymnia tubulosa, Ramalina farinacea, R. pollinaria,* and *Usnea dasopoga*). There were 43 species (35% of the lichen biota) included in the Polish national Red List (Cieśliński et al. 2006), including 16 with a high risk of extinction (CR + EN categories): *Arthonia arthonioides, A. byssacea, A. didyma, Bacidia biatorina, B. subincompta, Calicium adspersum, Cetrelia olivetorum, Chaenotheca stemonea, Chrysothrix candelaris, Cladonia parasitica, Flavoparmelia caperata, Lecanora intumescens, Loxospora elatina, Phaeophyscia endophoenicea, Pyrenula nitidella* and *Usnea subfloridana*. Most endangered species were found on the bark of oaks and beeches (Fig. 4).

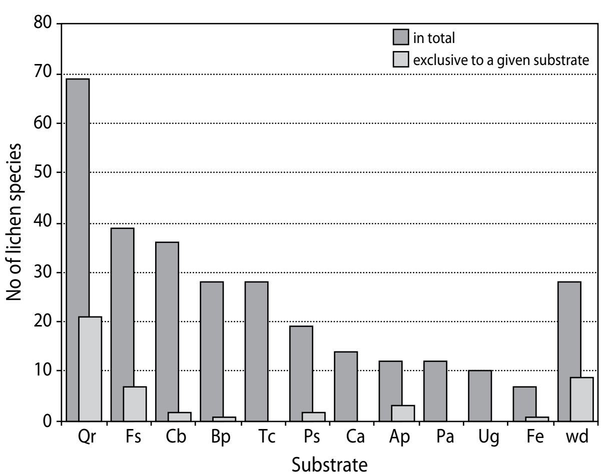

Figure 3. Number of lichen species recorded on specific substrates

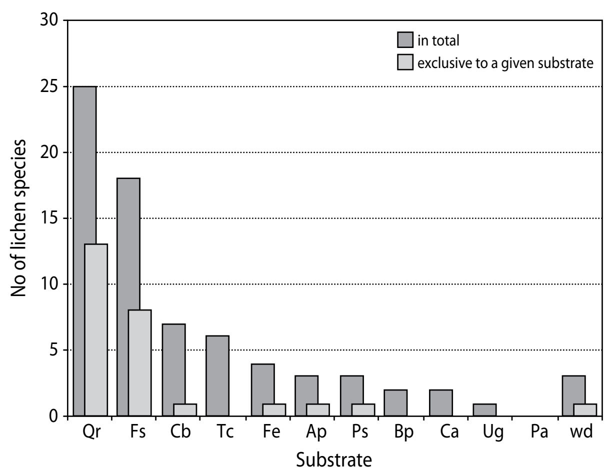

Figure 4. Number of lichen species included in the Polish national Red List recorded on specific substrates

The lichen biota of the "Sosny Taborskie" reserve includes 17 species that have the status of indicators of old-growth forests in Poland (Czyżewska and Cieśliński 2003), also referred to as forest relics (Cieśliński et al. 1996): *Arthonia arthonioides, A. byssacea, A. didyma, A. vinosa, Bacidia biatorina, Biatora ocelliformis, Calicium adspersum, C. viride, Cetrelia olivetorum, Chrysothrix candelaris, Cladonia parasitica, Fellhanera gyrophorica, Loxosopora elatina, Microcalicium dis-*

seminatum, Pertusaria pupillaris, Pyrenula nitidella and *Zwackhia viridis* (Tab. 1, Fig. 5). This group also includes some species of undetermined status, so far mainly recorded in well-preserved old forests: *Biatora mendax* (Kukwa et al. 2008), *B. hemipolia* (Kubiak and Łubek 2016), *Biatoridium monasteriense* (Łubek 2012), *Phaeophyscia endophoenicea* (Kubiak 2010), *Psoroglaena dictyospora* (Kubiak 2013a; Kukwa et al. 2020) and *Lecanora substerilis* (Malíček et al. 2017). The latter species is known in Poland only from two localities located in the Carpathians (Czarnota et al. 2018; Piegdoń and Szymczyk 2021). The locality of *L. substerilis* presented in this work is the first in the Polish lowlands.

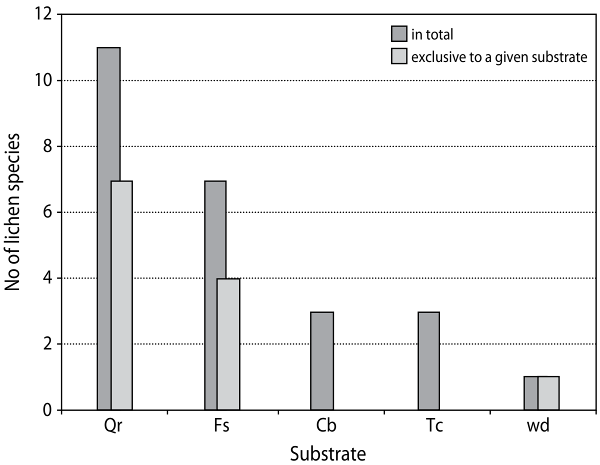

Figure 5. Number of lichen species classified as indicators of old-growth forest in Poland recorded on specific substrates

Discussion

Biodiversity inventories are undoubtedly an indispensable part of basic research and constitute one of the main challenges of conservation biology, especially given increasing threats related to global change processes. The classic approach is to describe the observed species richness (α-diversity) by a researcher (or a team of researchers) in a given time and space. Complete lists of species occurring in a given area can provide relevant specialists with a lot of valuable information, not ounly about the current state of local communities and their past. They also provide a wide range of possibilities for monitoring possible changes in the future. However, obtaining complete lists of species is very difficult, and may even be impossible (Vondrák et al. 2016). In order to limit this type of imperfections and the resulting errors, especially in the aspect of valorization and comparison of various objects, only selected species are often used, treated as a surrogate for the diversity of a given group of organisms or even overall diversity. Appropriate species of this type, also referred to as estimators of taxonomic diversity (TD; Cardoso et al. 2014), can be used not only to identify valuable areas but also to reflect local environmental conditions or biological phenomena (McCune 2000; Moning et al. 2009), including those that are too difficult, inconvenient, or expensive to measure directly (Rolstad et al. 2002). In the latter case, these must be species with known ecological requirements (preferably easy to observe) that make it easy to predict a responses to specific changes in the environment (Nitare 2019).

Due to their multi-faceted and complex relationships with the environment, lichens are a group of organisms commonly used for monitoring and valorization of forest areas (Kubiak 2013b). The occurrence of lichens in a forest community is determined by a number of factors, including the presence of a more or less specific substrate and the microclimatic conditions of the habitat (Ellis 2012). These conditions change with the age of the forest stand and the increasing internal diversity of the community. Old forest stands not only abound in a variety of microhabitats, crucial for the occurrence of many stenoecious species, but also provide stable conditions necessary for their development for a sufficiently long time (Rose 1976; Nordén et al. 2014; Łubek et al. 2020). As a result, many species growing in old-growth (and usually protected) forests are not found in commercial forests (Gustafsson 2002; Boch et al. 2013). Considering the huge disproportions between the current areas of these two types of forests, many species of old-growth forests are currently threatened with extinction on a national scale (Cieśliński et al. 2006). Forests corresponding to primary ecological systems are often the only places where so-called forest relics (Cieśliński et al. 1996) or old-growth forest indicators (Czyżewska and Cieśliński 2003) occur. These are species whose populations in a given area, sometimes now extinct, have survived in a few locations in the best-preserved parts of the communities, constituting a remnant of the forest biota, which was richer and more widespread in the past. The presence of this type of species (number and frequency) in a given forest complex constitutes important information not only about the current condition (health) of the forest but also about its past. It is therefore not surprising that lichen species constitute an important group of indicators among organisms used to determine the ecological continuity of forest communities (Rose 1976; Coppins and Coppins 2002). Taking into account the total number of species found and the number of rare and threatened stenoecious forest lichens, the "Sosny Taborskie" reserve can be included in the group of important biodiversity centers in NE Poland (Czyżewska and Cieśliński 2003). As part of the assessment of the diversity of the reserve's lichen biota (taking into account the previously mentioned limitations), it can be concluded that all analyzed lichenological indices (total number of species, number of species from the red list and number of old-growth forest indicators) have higher values than in many other sites of a comparable nature. A good example is the "Buki Wysoczyzny Elbląskiej" reserve, located in a region more optimal for beech vegetation. This reserve has an equally long history of protection and is characterised by a very good state of preservation of forest communities, dominated by the fertile lowland beech forest *Galio odorati-Fagetum*. The average age of the tree stands in this reserve is 146 years (most of the area is covered by older stands, aged 160–167 years). As a result of detailed research (Szymczyk et al. 2015), 102 species of lichens were found in this reserve, including 28 rare and threatened species and 10 old-growth forest indicators (Tab. 2).

However, this work does not provide detailed data for individual phorophytes. It seems that the main predictor of the greater diversity of the lichen biota in the "Sosny Taborskie" reserve, and especially the richness of stenoecious forest species, is the presence of old oak trees. On the bark of a relatively small number of oak trees, 10 indicator species of old-growth forests, including six exclusive ones, were found. Taking into account the relatively low age of the beech in the reserve, as well as the rather optimistic perspectives of this species on the border of its north-eastern range (Matuszkiewicz and Kowalska 2017), also in the aspect of predicted climate changes (Bolte et al. 2007), it can be expected that the number of lichens associated with this species will increase in the reserve. Beech forests are considered one of the most characteristic ecosystems of the temperate deciduous forest biome and are the habitat of many epiphytic lichens. The critical list of lichens associated with *F. slvatica* in Europe (prepared on the basis of data from 26 countries) includes 683 species (Hurtado et al. 2023), however, the range of the number of species in individual countries is very large (Hurtado et al. 2023). This is partly due to the uneven state of research in individual countries, but regional aspects (e.g. climate) are certainly also important. A total of 320 species of lichens associated with beech have been recorded in Poland so far (Hurtado et al. 2023), which constitutes nearly 20% of the total lichen biota (Fałtynowicz and Kossowska 2016). In some of the areas examined so far, located in the compact range of beech in the lowlands, this phorophyte contains the most species of epiphytic lichens (Schiefelbein et al. 2012), sometimes more than in the case of oak (Wieczorek and Łysko 2012). However, in areas located on the border or outside its compact

Table 2. The number of lichens – indicators of lowland old-growth forest recorded in selected national parks (NP) and nature reserves (NR) in Poland

Parks and nature reserves	Białowieża NP	Budzisk NR	Las Warmiński NR	Starożyn NR	Borki NR	Sosny Taborskie NR	Pupy NR	Buki Wysoczyzny Elbląskiej NR	Dolina rzeki Wałszy NR	Starodrzew Szyndzielski NR	Kadyński Las NR
Area [ha]	10242	328	1798	298	440	95	58	94	205	79	8
No. of species	60[1,2]	34 [1]	30 [3]	30[1,4]	29[1]	17	12[5]	10[6]	8[7]	8[8]	4[9]

[1] Czyżewska and Cieśliński (2003); [2] Kukwa et al. (2008); [3] Kubiak and Sucharzewska (2012); [4] Czyżewska et. al. (2005); [5] Kubiak et al. (2017); [6] Szymczyk et al. (2015) [7] Szydłowska et al. (2013);[8] Kolanko (2009); [9] Szymczyk et al. (2016).

range, beech is characterized by a relatively low number of associated lichens, usually not exceeding 40 taxa (Tobolewski 1952; Hutorowicz 1957). In this context, considering the relatively young age of the beech trees in the reserve, the diversity of the lichens associated with it can be considered relatively high. The results of research on the chronosequence of beech epiphytic lichens indicate a significant increase in the number of species over 140 years old (Moning and Müller 2009), i.e. above the optimal rotation (harvesting) age for this species adopted in commercial forests. Many stenoecious lichens associated with beech forests grow on even older trees, over 180 years old (Fritz et al. 2008). Kaufmann et al. (2018) have indicated, however, that the trunk diameter is a more important factor influencing the diversity of epiphytes than the actual age of the tree. However, with age, specific tree-related microhabitats (TreM) are formed. This term means a distinct, well-delineated morphological singularity occurring on living or standing dead trees (dead branches, tree holes, leaning trees, etc.), which constitutes a crucial substrate or life site for various species (Larrieu et al. 2018). Unlike pioneer and short-lived species, long-lived and shade-tolerant trees, such as beech and oak, acquire a greater number of these types of features key to species diversity only after reaching an appropriately advanced age (Larrieu et al. 2021).

When analyzing the current state of lichen biota in the reserve, it is impossible to avoid the question about the importance of pine. Its direct role as a substrate for epiphytic lichens is small, but its presence undoubtedly affects the structure of the tree stand and local microclimatic conditions, which is certainly important for the entire biota and lichens associated with individual phorophytes. However, this issue requires further detailed research. A pan-European study by Pretzsch et al. (2015) have shown that in the case of mixed stands of Scots pine and European beech, we can expect a significant overall increase in productivity compared to analogous single-species stands. It should be noted that this type of species complementarity is possible mainly in pine populations in the most humid habitats (González de Andrés et al. 2018). Mixing species is one of the proposed forestry models in response to expected restrictions in the cultivation of certain species resulting from climate change (Pretzsch et al. 2015; Sebald et al. 2021).

The obtained results not only document and confirm the above-average importance of this area for the protection of the diversity of forest lichens in supra-regional scale, but the results also address the most current forestry problems. They prove that under certain specific conditions, mixing tree species with complementary ecological traits may modify forest functioning not only in terms of productivity, stability, or resistance against disturbances (Pretzsch et al. 2016), but also general biodiversity, and more precisely, the diversity of lichens.

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