VERSITA
DOI: 10.2478/frp-2013-0024

Leśne Prace Badawcze (*Forest Research Papers*),
September 2013, Vol. 74 (3): 245–255.

ORIGINAL RESEARCH ARTICLE

The significance of old-growth forests in maintaining lichen diversity – an example from the remnants of the Mazovian Forest

Dariusz Kubiak

University of Warmia and Mazury in Olsztyn, The Faculty of Biology and Biotechnology, Department of Mycology, ul. Oczapowskiego 1A, 10-719 Olsztyn, Poland.

Tel. +48 89 5234297, e-mail: darkub@uwm.edu.pl

Abstract. The paper presents the results of a lichenological study conducted in 2012 in the 'Lekowo' forest complex, situated in the north-western part of Mazovia (Forest Division of Ciechanów). It is the largest forest complex in the area, covering 1596 ha. The research area comprises two small nature reserves ('Lekowo' – 5,31 ha, and 'Modła' – 9,36 ha) with old-growth oak trees (160–200 years of age) and adjacent managed pine forests (76–107 years of age). The aim of this study was to investigate the species composition of the lichen biota in both reserves and to determine the role of nature reserves in preserving lichen diversity. Results of the study showed that old-growth stands, in particular those composed of oak trees above recommended felling age, provide habitats for a large group of stenotopic forest lichens which are absent in managed forests. The 'Lekowo' and 'Modła' nature reserves, despite their small areas, are valuable refuges that help to conserve remarkable lichen diversity at the local scale, and serve as potential diaspore sources for many rare and threatened lichen species.

Key words: lichens, species diversity, fragmentation, nature conservation, forest management, lichen indices

1. Introduction

Forests covered almost the entire geographical area of Poland in the past. Forest area, which covered 40% of the country in the 18th century (within boarders of that time), decreased to 20,8% in 1945. Deforestation accompanied by impoverishment of forest stand species structure caused decreasing of biodiversity in forests. Even though forest area in Poland increased by 29,2% between 1945–2010, the possibility of extinction of many organisms in the forest ecosystem looms large. Lichens are the most endangered in the group of plants and fungus. 886 of 1600 species found in Poland were registered on the Red List of threatened lichens (Cieśliński et al. 2006).

Lichens connected with natural forest habitats are especially threatened (Cieśliński, Czyżewska 1992; Czyżewska 2003). It is estimated that there are at least 600 species of lichens in Polish forests (Fałtynowicz 2006). Many of them are highly specialised organisms and susceptible to changes of ecological conditions. Occurrence and distribution of lichens are often limited to old forest stands grown within the largest forest complexes in Poland (Cieśliński, Tobolewski 1988; Cieśliński et al. 1996; Czyżewska, Cieśliński 2003; Kubiak, Sucharzewska 2012).

The main factors responsible for impoverishment of lichens' diversity in forests, and for reducing of many rarely stenotopic species, is:

– decreasing of forest area during several centuries,
– decreasing of forest stands age,
– simplification of the structureand internal variety of natural habitats,
– forest fragmentations,

and as a result of it, isolation of local species populations (Hawksworth et al. 1974; Cieśliński, Czyżewska 1992;

Received 13 March 2013, accepted after revision 18 June 2013

Czyżewska, Cieśliński 2003; Otálora et al. 2011; Brunialti et al. 2013).

There are not so many studies in Poland on the influences of forest management on lichens (Fabiszewski 1968; Fałtynowicz 1986; Cieśliński 2008; Kościelniak 2008). Moreover, in many regions there is a noticeable lack of basic research documenting species compositions of forest complexes (cf. Kubiak, Szczepkowski 2012). There are also not so many studies analysing lichens appearance in particular forest habitats, and especially, in diverse, defined forms of forests anthropogenic degeneracy (Cieśliński et al. 1995; Czyżewska, Cieśliński 2003).

The aim of this study was to investigate the species compositions of lichen biota in two forest reserves placed in the northwest part of Mazowsze (Mazovia region), and to determine a potential significance of these reserves in preserving lichens diversity; as regards analysed areas, there has not been any lichenological data.

2. Research methods and materials

Research plots

The research area was in 'Lekowo', the largest forest complex of the Forest Division of Ciechanów, covering 1596 ha. The analysed research is conducted 10 km northwest from Ciechanów, on the southern border of Mławskie Hills (Kondracki 2013). It is a remnant of the former Mazovian Forest. Until 1945 most of the forest area, that is now included in the Forest Division of Ciechanów, was a private property. The 'Lekowo' complex was included into the Krasińscy's Opinogórska Entail (Dróżdż, Sarnowski 2004).

Agricultural areas dominate the territorial range of the Forest Division of Ciechanów. Afforestation rate of the area is 14,4%. Private forests constitute over 42% of the forest area (Dróżdż, Sarnowski 2004). As a result of human activities, natural forest habitats were heavily transformed. Substitute, secondary forest communities (one or multi-species, one-storey structure) dominate. Forest stands consist of pines cultivated on almost all types of habitats, including formerly arable lands. In the after war time, pine was often planted without proper identification of soil conditions. In effect, pine stands cover nowadays most of forest habitats, which are 34,9% of the Forest Division of Ciechanów. Forests are characterised by a low share of older age class, and in habitats inventoried between 2006–2007 full-grown forest stands are only 14,7% ('Prognosis of Forest Management Plan influence on environment for the years 2004–2013'). Most of them are places in the area of the 'Lekowo' complex. Two primary forests remained in the complex are protected as small nature reserves 'Lekowo' (5,31 ha) and 'Modła' (9,36 ha) from 1979. The majority of the area is dominated by stand with old-growth oak trees (160–200 years of age). It grows in fresh broadleaved forest habitat where a lime-oak-hornbeam forest *Tilio cordatae-Carpinetum betuli calamagrostietosum* was formed ('Prognosis of Forest Management Plan influence on environment for the years 2004–2013'). These habitats have remained because of hunting management that was run in this area in the past. It is still a wilderness for forest game that forms forest communities of both reserves to a high degree.

Fieldwork

Fieldwork was conducted in 2012. It covered an area of two nature reserves and adjacent managed pine forests

Table 1. The characteristic of the research plots in the 'Lekowo' forest complex

Research plot No.	Forest compartment	Area (ha)	Dominant tree species (age)	Forest community	Form of protection
I	148 d, i	5,31	Db 197	*T.-C. c.*	'Lekowo' reserve
II	164 b, c, d	9,36	Db 197 (So 106, Db 66)	*T.-C. c*	'Modła' reserve
III	159 b	15,56	So 107	*T.-C. c*	-
IV	147 b	17,51	So 82	*T.-C. c*	-
V	137 f	15,80	So 76	*T.-C. c*	-

Abbreviations: Db – oak, So – pine, *T.-C. c – Tilio cordatae-Carpinetum betuli calamagrostietosum*

(76–107 years of age) grown on similar habitats (secondary forest communities). A topographic method was applied. Several transects were marked out in the area of selected forest compartments (Table 1). Then, during a walk along the selected route, encountered lichens species on all substrates colonised by these organisms were registered. Species identified in the field were catalogued without taking any specimens for further reference. Regarding remaining taxa, small fragments of thallus were taken for further taxonomic analysis in a laboratory.

Laboratory work

Collected material was identified according to standard procedures that include detailed microscopic observation, spot tests, and biochemical analysis differentiates secondary metabolites of lichen fungi (cf. Smith et al. 2009). Thin Layer Chromatography (TLC) analysis was conducted in the Department of Mycology of the University of Warmia and Mazury in Olsztyn according to procedures presented in Kubiak and Kukwa's studies (2011). Remaining herbarium specimens were included in lichens collections of the Department of Mycology (OLTC). Species nomenclature was after Fałtynowicz (2003) and Index Fungorum (2013). Threatened categories of lichens follow Cieśliński et al. studies (2006). List of lichens, indicators of lowland old-growth forests follows Czyżewska and Cieśliński's studies (2003).

Statistical analysis

To determine similarities between the species composition in lichens biota of individual plots, hierarchical accumulating classification were performed by means of MVSP Package (Kovach 2010). To form a dendrogram, Unweighted Pair Group Method with Arithmetic Mean (UPGMA) was used, and Euclidean space was used as similarity measures. Epiphytic and epixylic lichens species, connected with forest environment, were analysed. However, epilithic taxa were omitted. To determine the statistical significance of differences between mean values of analysed numerical characteristics of both types of communities (Fig. 2), a *t*-test was applied to independent samples (statistical significance $p \leq 0{,}05$). Statistical analysis was made in the program Statistica 10 (StatSoft Polska).

3. Results

83 lichens taxa (73 in nature reserves and 53 in managed forest) were identified in research plots (Table 2).

Research conducted indicated clear differences between lichen biota of both types of analysed forest communities (Fig. 1). In nature reserves, compared to managed forest, more epiphytic species were identified. These were taxa included in the Red List and under the legal protection in Poland. There were also more taxa-indicators of lowland old-growth forests (Fig. 2). Differences between all analysed numerical parameters are statistical significant.

Notable domination of epiphytic species (77 taxa) in lichens biota of 'Lekowo' complex was observed. Among them, 68 identified taxa were in nature reserves and 49 in managed forests. The highest diversity of lichens was observed on oak bark – 63 species (57 in nature reserves and 33 in managed forests), and: on hornbeam bark – 24, pine – 17, birch – 15, spruce – 5, and

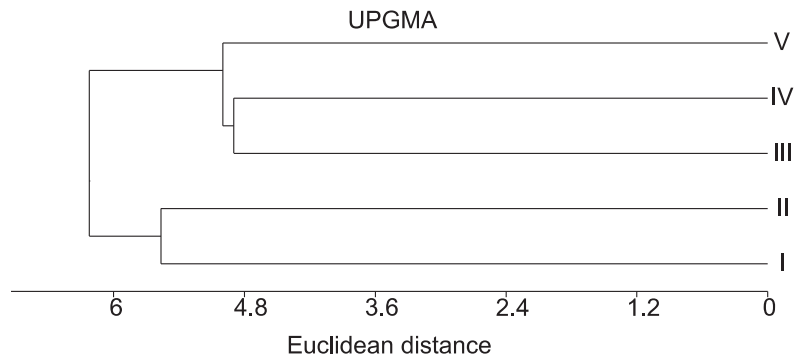

Figure 1.
Dendrogram showing similarity between lichen biota in the analyzed research plots (I-II – nature reserves, III-V – managed forests)

Table 2. List of lichens of the 'Lekowo' forest complex

Species	Research plot					Bioecological group	Status of the species
	I	II	III	IV	V		
	nature reserves		managed forests				
Absconditella lignicola Vězda & Pišút	+	.	+	+	.	Ek	.
Agonimia cfr. *repleta* Czarnota & Coppins	+	.	.	.	+	Ep	.
Amandinea punctata (Hoffm.) Coppins & Scheid.	+	.	.	.	.	Ep	.
Anisomeridium polypori (Ellis & Everh.) M.E. Barr	+	+	+	.	+	Ep	.
Arthonia byssacea (Weigel) Almq.	.	+	.	.	.	Ep	EN, WNLP
A. muscigena Th. Fr.	.	+	+	.	.	Ep	.
A. radiata (Pers.) Ach.	.	.	.	+	.	Ep	.
A. ruana A. Massal.	+	+	.	.	.	Ep	NT
A. spadicea Leight.	+	+	+	.	.	Ep	.
Bacidia rubella (Hoffm.) A. Massal.	+	.	+	.	.	Ep	VU
B. subincompta (Nyl.) Arnold	+	+	.	.	.	Ep	EN
Bacidina chlorotica (Nyl.) Vězda & Poelt	+	.	.	.	.	Ep	.
B. sulphurella (Samp.) M. Hauck & V. Wirth	+	+	+	+	+	Ep	.
Biatora efflorescens (Hedl.) Räsänen	.	.	+	+	.	Ep	VU
Buellia griseovirens (Turner & Borrer ex Sm.) Almb.	+	+	.	.	+	Ep	.
Calicium adspersum Pers.	+	+	.	.	.	Ep	EN, WNLP
C. salicinum Pers.	+	.	.	.	.	Ep	VU
C. viride Pers.	+	+	.	.	.	Ep	VU, WNLP
Candelariella cfr. *efflorescens* R.C. Harris & W.R. Buck	+	+	.	.	.	Ep	.
Chaenotheca chlorella (Ach.) Müll. Arg.	+	.	.	.	.	Ek	CR, WNLP
Ch. chrysocephala (Ach.) Th.Fr.	.	+	.	.	.	Ep	.
Ch. ferruginea (Turner ex Sm.) Mig.	+	+	+	+	+	Ep	.
Ch. furfuracea (L.) Tibell	.	.	.	+	.	Ep	NT
Ch. Stemonea (Ach.) Müll. Arg.	+	.	+	+	.	Ep	EN
Ch. Trichialis (Ach.) Hellb.	+	+	.	+	+	Ep	NT
**Chaenothecopsis pusilla*(A. Massal.) A.F.W. Schmidt	+	.	.	.	+	Ep, Ek	.
Chrysothrix candelaris (L.) J.R. Laundon	+	+	.	.	.	Ep	Os, CR, WNLP
Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.	.	.	.	+	.	Ep	.
C. coniocraea (Flörke) Spreng.	+	+	+	+	+	Ep, Ek	.
C. digitata (L.) Hoffm.	.	+	.	+	.	Ep	.
C. fimbriata (L.) Fr.	+	+	+	.	.	Ep	.
C. macilenta Hoffm.	.	+	+	+	.	Ep	.
C. ochrochlora Flörke	.	.	+	.	.	Ep	.
Coenogonium pineti (Schrad.) Lücking & Lumbsch	+	+	+	+	+	Ep	.
Evernia prunastri (L.) Ach.	+	.	.	+	.	Ep	Oc, NT
*Fuscidea pusilla*Tønsberg	+	+	.	.	.	Ep, Ek	.
Graphis scripta (L.) Ach.	+	+	.	.	.	Ep	NT
Hypocenomyce scalaris (Ach. ex Lijl.) M. Choisy	+	+	+	+	+	Ep	.
Hypogymnia physodes (L.) Nyl.	+	+	+	+	+	Ep	.
H. tubulosa (Schaer.) Hav.	+	.	.	.	.	Ep	Os, NT
Lecanora carpinea (L.) Vain.	.	.	.	+	.	Ep	.
L. chlarotera Nyl.	+	.	.	.	.	Ep	.
L. conizaeoides Nyl. ex Cromb.	+	+	+	+	+	Ep	.

Species	Research plot					Bioecological group	Status of the species
	I	II	III	IV	V		
	nature reserves		managed forests				
L. expallens Ach.	+	+	+	+	+	Ep	.
L. pulicaris (Pers.) Ach.	.	.	.	.	+	Ep	.
L. rugosella Zahlbr.	.	.	.	+	.	Ep	.
L. thysanophora R.C. Harris	+	+	+	.	.	Ep	.
Leprariaelobata Tønsberg	+	+	+	+	+	Ep, Ek, El	.
L. incana (L.) Ach.	+	+	+	+	+	Ep, Ek, El	.
L. jackii Tønsberg	.	+	+	+	.	Ep	.
L. lobificans Nyl.	+	+	+	+	+	Ep	.
L. vouauxii (Hue) R.C. Harris	+	+	.	.	.	Ep	.
Melanelixia glabratula (Lamy) Sandler & Arup	+	+	+	+	.	Ep	Os
Micarea botryoides (Nyl.) Coppins	.	+	.	.	.	Ep	.
M. lithinella (Hyl.) Hedl.	.	.	.	+	.	El	.
M. prasina s.l.	+	+	+	+	+	Ep, Ek	.
**Microcalicium dissemnatum* (Ach.) Vain.	+	+	.	.	.	Ep	WNLP
Opegrapha varia Pers.	+	+	+	.	.	Ep	NT
Parmelia saxatilis (L.) Ach.	.	+	.	.	.	Ep	Os
P. sulcata Taylor	+	+	+	+	+	Ep	.
Parmeliopsis ambiqua (Wulfen) Nyl.	+	.	.	.	.	Ep	Os
Pertusaria albescens (Huds.) M. Choisy & Werner	+	+	+	.	.	Ep	.
P. amara (Ach.) Nyl.	.	.	+	.	.	Ep	.
P. leioplaca DC.	.	+	.	.	.	Ep	NT
Phlyctis argena (Ach.) Flot.	+	+	+	+	+	Ep	
Physcia tenella (Scop.) DC.	+	+	.	+	.	Ep	.
Physconia enteroxantha (Nyl.) Poelt	+	+	.	.	.	Ep	.
Placynthiell adasaea (Stirt.) Tønsberg	+	+	.	.	+	Ep	.
P. icmalea (Ach.) Coppins & P. James	+	+	+	+	.	Ep, Ek	.
Platismatia glauca (L.) W.L. Culb. & C.F Culb.	.	+	.	.	.	Ep	Os
Porina aenea (Wallr.) Zahlbr.		+	+	+	.	Ep	.
P. chlorotica (Ach.) Müll. Arg.	+	.	+	.	+	El	.
Protoparmelia hypotremella Herk, Spier & V. Wirth	+	+	.	.	.	Ep	.
Psoroglaena dictyospora (Orange) H. Harada	+	.	.	.	.	Ep	.
Ramalina farinacea (L.) Ach.	+	+	.	+	.	Ep	Os, VU
R. pollinaria (Westr.) Ach.	+	+	+	.	.	Ep	Os, VU
Rinodina degeliana Coppins	+	.	.	.	.	Ep	.
R. efflorescens Malme	+	.	.	.	.	Ep	.
Ropalospora viridis (Tønsberg) Tønsberg	+	.	.	+	.	Ep	.
Scoliciosporum chlorococcum (Graewe ex Stenh.) Vězda	+	.	.	+	.	Ep	.
Trapelia placodioides Coppins & P. James	.	.	.	+	.	El	.
Trapeliopsis granulosa (Hoffm.) Lumbsch	.	+	.	.	.	Ep, Ek	.
Verrucaria sp.	+	.	.	.	.	El	.
total:	60	52	34	37	22	.	.

Abbreviations: Ep – epiphyt, Ek – epixylith, El – epilith, Os – strict protection, Oc – partiall protection, CR – critically endangered, EN – endangered, VU – vulnerable, NT – near threatened, LC – least concern, DD – data deficient, WNLP – indicator of lowland old-growth forests, * – saprothrophic or parasitic (lichenicolous) fungus

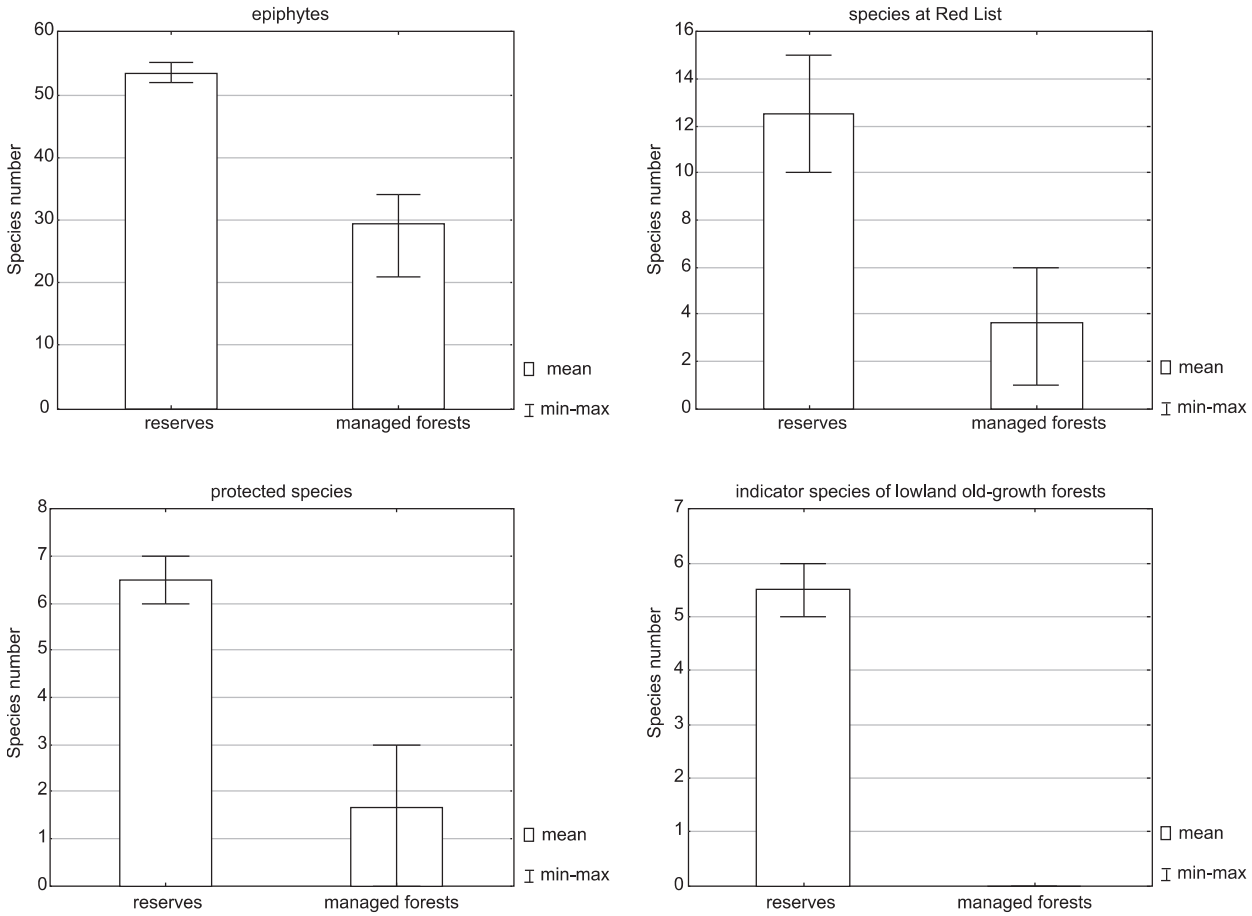

Figure 2. Average and minimum and maximum number of species in each group recorded in the reserves and managed forests

lime – 3. Share of lichens of other ecological groups was negligible. 10 epixylic taxa were identified (including two: *Absconditella lignicola* and *Chaenotheca chlorella*) and 6 epilithic taxa growing on small stone and rocks (including four: *Micarea lithinella*, *Porina chlorotica*, *Trapelia placodioides* and *Verrucaria* sp.). Lichens grown on ground were not found because of lack of proper habitats.

20 species placed on the Red List were identified together in all research plots. In this group, 11 taxa were found in nature reserves and 9 in managed forests. Furthermore, 9 identified taxa are protected in Poland, 8 under strict protection and 1 under partial protection. 9 taxa of the type were identified in nature reserves and 4 in managed forests. Only 5 taxa of protected species are also organisms placed on the Red List in Poland: *Chrysothrix candelaris* (category CR), *Evernia prunastri* (NT), *Hypogymnia tubulosa* (NT), *Ramalina farinacea* (VU), and *R. pollinaria* (VU).

Compared to adjacent managed forests, lichens biota of nature reserves were characterised by the presence of rare lichens critically endangered in Poland. In nature reserves, two critically endangered species were found CR – *Chaenotheca chlorella* and *Chrysothrix candelaris*, and three endangered – EN – *Arthonia byssacea*, *Bacidia subincompta,* and *Calicium adspersum*, that are absent in managed forests. Furthermore, there were 6 species, indicators of lowland old-growth forests, identified and were absent in managed forests: *Arthonia byssacea*, *Calicium adspersum*, *C. viride*, *Chaenotheca chlorella*, *Chrysothrix candelaris,* and *Microcalicium disseminatum*. Several interesting taxa were found in nature reserves of poorly recognised distribution and status in Poland: *Bacidina chlorotica*, *Fuscidea pusilla*,

Protoparmelia hypotremella, Psoroglaena dictyospora, Rinodina degeliana, and *R. efflorescens*. Barks of the oldest oaks were the only habitats for aforementioned species, with the exception of *Chaenotheca chlorella* and *Fuscidea pusilla*.

Lichens diversity identified in managed forests was significantly lower than in nature reserves. On pine that dominated in a forest stand, only 14 taxa were found. Significantly higher number of species was identified on a bark of deciduous trees, first of all on oak bark (33 taxa), and then birch (15) and hornbeam (12). Lichens biota of managed forests consisted of 14 taxa common for all research plots – *Bacidina sulphurella*, *Chaenotheca ferruginea*, *Cladonia coniocraea*, *Coenogonium pineti*, *Hypocenomyce scalaris*, *Hypogymnia physodes*, *Lecanora conizaeoides*, *L. expallens*, *Lepraria elobata*, *L. incana*, *L. lobificans*, *Micarea prasina* s.l., *Parmelia sulcata,* and *Phlyctis argena*. These lichens can be recognised as being common in the analysed area. In the managed forests, few rare taxa were found that are placed on the Red List, but in most cases they represent low threat categories. In this group *Biatora efflorescens* (VU) and *Chaenotheca furfuracea* (NT) were not found in nature reserves. Several species were identified in managed forests that are interested regarding taxonomy and ecology issues, for instance: *Absconditella lignicola*, *Agonimia repleta*, *Arthonia muscigena*, *Bacidina sulphurella*, *Lecanora thysanophora,* and *Ropalospora viridis*. Aforementioned lichens were also found in nature reserves.

4. Discussion

Biological diversity of forest ecosystems depends on their naturalness (Jaroszewicz 2007). Regarding some groups of organisms like lichens, it is particularly significant factor (Cieśliński, Tobolewski 1988; Cieśliński et al. 1996; Dettki, Esseen 1998; Lesica et al. 1999; Czyżewska, Cieśliński 2003; Kubiak, Sucharzewska 2012). It is influenced by high diversity of habitat conditions in natural forests and limited range of diasporas dispersion of many lichens species, as well as by long-lasting process of colonizing new habitats by lichens (Werth 2005 and literature there in; Fritz et al. 2008). The research conducted in the 'Lekowo' complex proved that old-growth forests in the 'Lekowo' and 'Modła' nature reserves are characterised by higher diversity of lichen biota than it is in adjacent managed forests. These forests reveal some characteristics of natural regeneration as for example deciduous species in a lower stand level. It occurs in spite of clear signs of human management activities (low species and stand age diversity) in the old-growth forests.

Regarding other, comparable areas in Poland, species diversity of lichens in the 'Lekowo' and 'Modła' nature reserves can be recognised as moderately high. Total number of species is significantly lower than the number observed in similar areas located in the northeast part of Poland (Kolanko 2009; Kubiak 2011), but it is significantly higher than in areas of central Poland (Kubiak, Szczepkowski 2006, 2012). It is coherent with the tendency observed in Poland that lichens diversity in similar ecological systems decreases in west and southwest direction (Czyżewska 2003).

Regarding the region, it is difficult to conduct general evaluation of lichens diversity in the 'Lekowo' and 'Modła' nature reserves and other researched parts of the forest complex 'Lekowo' because of shortage of proper lichenological studies. The 'Dziektarzewo' Nature Reserve is the only nature reserve within forest reserves in the northwest part of Mazovia, protecting remains of natural forests, where detailed lichenological studies have been conducted (Kubiak 2009). Sixty eight lichen species have been identified in a small area of the nature reserve (5,35 ha), including large group of rare forest lichens. However, comparisons between the 'Dziektarzewo' Nature Reserve and the 'Lekowo' are unjustified because of different ecological conditions of the 'Dziektarzewo' Nature Reserve. It is partially located on a steep slope of the Wkra Valley. Favorable influence of river valleys on increasing local species diversity of lichens has been indicated many times (Kubiak 2009, and literature there in). There is lack of data about lichens species resources in managed forests of this part of Poland.

Nature reserves located in the 'Lekowo' forest complex are characterised by lichens included in the group of indicators of lowland old-growth forests (cf. Czyżewska, Cieśliński 2003; cf. Cieśliński 2003). Nature reserves are the only sanctuary of these species both in the 'Lekowo' forest complex and probably in all the Forest Division of Ciechanów. An influence of different factors on presence and absence of stenotopic lichens in forests has been discussed in many studies (Fabiszewski 1968; Cieśliński et al. 1996; Czyżewska, Cieśliński 2003; Kubiak, Sucharzewska 2012). Stand age is one of the most important factors. Old age of individual trees and bark properties changing with age enable appearance of epiphytic lichens that are absent in forest stands (for

example in managed forests) consisting only of young trees. Oaks are significantly important for lichens' diversity because of broad ecological scale and the long age of individual trees. Oaks are characterised by the most diverse and to a high degree, specific lichen biota within other, main forest-forming species (Fałtynowicz 2003; Kubiak, Sucharzewska 2012, and literature there in). The whole scale of the aforementioned diversity is rarely observed in forests because of small number of oaks over mature age, particularly, trees in the process of natural withering. The 'Lekowo' and 'Modła' nature reserves, as many other reserves in Poland, cover small area, and probably, do not also provide optimal growing conditions for stenotopic lichens identified in the area. Besides small area, their shape seems to influence negatively lichens vegetation. The shape is similar to rectangle in both reserves. Width of the longer side is 32–185 m in the 'Lekowo' and 190–245 m in the 'Modła' Nature Reserve. According to Cieślak (1996), external disturbances around the forest reach up to 200 m into the forest. Only the forest over 400 m can have character of the typical forest inner part (Jankowski 2001). Therefore, the area of both reserves seems to be too small to create conditions for microclimate occurrence, characteristic for inner parts of natural forests (Fritts 1961; Chen et al. 1999; Brosofske et al. 2007). Norris et al. (2012), based on studies carried out in several regions in Europe, has claimed that microclimate of old forests is characterised i.e. by lower amplitude of the mean daily temperature and higher mean relative humidity than microclimate of adjacent managed forests of similar stand structure. Though, the 'Lekowo' and 'Modła' nature reserves are surrounded by juvenile and maturing stands, pine and pine-birch forests (age classes II and III). Forest divisions with older pine stands (age class VI – division 158a) and oak stands (mature and over-mature age class – division 157c) only remain in the vicinity of the 'Modła' nature reserves. Therefore, many lichens' species that occur on the tree bark of the oldest oaks cannot find proper conditions for growing, apart from protected sanctuary areas. Lack of data, which could help determine minimal area to provide living space for individual lichens species, is notable. Studies conducted in Sweden have shown that small forest areas of 0,01–0,5 ha are too small to preserve the diversity of lichens for a long period of time (Perhans et al. 2009). The size of the area is important even in spite of preserving stand structure characteristics for natural forests and in spite of diverse habitats and substratum. In parts of old-growth forests and in regard to an edge effect, the area suitable to colonize is smaller for many species than the total area of these parts (Sławski 2008).

As a result of fragmentation of habitats, there occurs fragmentation and isolation of the species' populations. Isolation blocks biological processes, especially, gene flow between individuals that determine stability of meta-population (Young, Clarke 2000; Werth 2005). Regarding epiphytic lichens dominating in the forest, 'local population' can be understood as all thallus of the species that grow on an individual tree, and 'metapopulation' – as a group of all local populations in the selected forest landscape (Fedrowitz et al. 2012). In managed forests, in extreme cases like a cluster of old trees surrounded by forests cultivations, the notion of the 'forest landscape' are limited to an individual division. Then, these are very small populations that have a tendency to losing genetic diversity, and in consequence, ability to adjust to changing environment (Pullin2004).

The range of species dispersion by means of different diasporas is a factor that, to a high degree, decides if individual species can populate new habitats in specific conditions. Negative influence of forest fragmentation on lichens results from limited spread range that usually does not go over 100 m (Öckinger et al. 2005; Scheidegger, Werth 2009; Juriado et. al. 2011). Regarding many species, this characteristic significantly limits the species' ability to overcome environmental barriers and to populate new habitats (Selva 1994; Gu et al. 2001).

Results of research on *Lobaria pulmonaria* have proved that genetic diversity of the population in old forests is significantly higher than in younger forests (managed forests) (Juriado et al. 2011; Otálora et al. 2011). The significance of old-growth forests in maintaining biological diversity is high. Protecting overmature forest stands and seed-trees (individual old trees) is the first and basic condition of endangered forest lichens preservation. It is significantly important because of the fact that possibilities of active protection of lichens by thallus meta-plantations or vegetative diasporas seem to have limited application. Attempts made so far have concerned small number of taxa, mostly of fruticose and foliose types (Scheidegger et al. 1995; Sillet, McCune 1998; Linden et al. 2004). Many authors have emphasised the significance of protected areas in maintaining lichens diversity in forests (Cieśliński 2008; Wieczorek 2009). Regarding the fact that stands adjacent the 'Lekowo' and 'Modła' nature reserves reveal tendency towards natural regeneration

in the direction of wet ground forests, two solutions should be taken into account: an extension of the area by connecting both reservesor creating protection zones around them to reduce negative effect of too small isolated area.

Plan to established Special Area of Conservation NATURE 2000 'Ciechanowskie Grądy' in the 'Lekowo' forest complex seems to be one of alternatives. It should aim at protecting habitats and wet ground forests, which already existed in the area (Kepel 2000).

5. Conclusions

Results of the study showed that old-growth stands, above the felling age, in particular those composed of oak trees, provide habitats for a large group of stenotopic forest lichens which are absent in managed forests. Regarding other researched parts of 'Lekowo' forest complex, the 'Lekowo' and'Modła' nature reserves are distinguished by both higher lichens diversity and larger number of rare forest lichens species. In the area of the 'Lekowo' (and probably in the whole area of the Forest Division of Ciechanów), both nature reserves are the only places of indicators of lowland old-growth forests occurrence. The 'Lekowo' and 'Modła' nature reserves are both valuable sanctuaries for local species diversity and the diasporas source of many rare and endangered lichens species. To conserve the diversity, it is advisable to aim at increasing protected areas by connecting nature reserves, even if natural qualities of the stands do not meet adequate conservatory criteria.

Acknowledgements

I would like to thank Reviewers for their essential remarks that contributed to creating the final version of the paper. The research was financed from statutory research funds by the Department of Biology and Biotechnology, the University of Warmia and Mazury in Olsztyn (No.: 0211-0802).

References

Prognoza oddziaływania na środowisko Planu Urządzenia Lasu na lata 2004-2013. Nadleśnictwo Ciechanów, RDLP W Olsztynie. Biuro Urządzania Lasu i Geodezji Leśnej w Olsztynie, Olsztyn.

Brosofske K.D., Chen J., Naiman R.J., Franklin J.F. 1997. Effects of harvesting on microclimatic gradients from streams to uplands in western Washington, USA. *Ecological Applications*, 7: 1188–1200.

Brunialti G., Frati L., Loppi S. 2013. Fragmentation of Mediterranean oak forests affects the diversity of epiphytic lichens. *Nova Hedvigia*, 96 (1–2): 265–278.

Chen J., Saunders S.C., Crow T.R., Naiman R.J., Brosofske K.D., Mroz G.D. et al. 1999. Microclimate in forest ecosystem and landscape ecology. *BioScience*, 49 (4): 288–297.

Cieślak M. 1996. Zagrożenia i kierunki ochrony różnorodności biologicznej rozdrobnionych lasów. Instytut Ochrony Środowiska, Warszawa, p. 34. ISBN 9788385805281.

Cieśliński S. 2003. Atlas rozmieszczenia porostów (Lichenes) w Polsce północno-wschodniej [Distribution atlas of lichens (Lichenes) in North-Eastern Poland]. *Phytocoenosis*, 15 (N.S.). *Supplementum Cartographiae Geobotanicae*, 15: 1–430.

Cieśliński S. 2008. Znaczenie ochrony rezerwatowej dla zachowania bioty porostów (Ascomycota lichenisati) w Puszczy Kozienickiej [The Role of nature reserves in conservation of the lichen biota (Ascomycota lichenisati) in Kozienicka Primeval Forest]. *Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej,* 10, 3 (19): 99–109.

Cieśliński S., Czyżewska K. 1992. Problemy zagrożenia porostów w Polsce [Problems of threatened lichenized fungi in Poland]. *Wiadomości Botaniczne*, 36 (1–2): 5–17.

Cieśliński S., Czyżewska K., Fabiszewski J. 2006. Red list of the lichens in Poland. In: Mirek Z., Zarzycki K., Wojewoda W., Szeląg Z. (eds.) Red list of plants and fungi in Poland. Kraków, W. Szafer Institute of Botany, PASc.: 71–89.

Cieśliński S., Czyżewska K., Faliński J. B., Klama H., Mułenko W., Żarnowiec J. 1996. Relicts of the primeval (virgin) forest. Relict phenomena. In: Faliński J.B., Mułenko W. (eds.) Cryptogamous plants in the forest communities of Białowieża National Park (Project CRYPTO 3). *Phytocoenosis*, 8 (N.S.), *Archivum Geobotanicum*, 6: 197–216.

Cieśliński S., Czyżewska K., Glanc K. 1995. Lichenes. In: Faliński J.B., Mułenko W. (eds.) Cryptogamous plants in the forests communities of Białowieża National Park. General problems and taxonomic groups analysis (Project CRYPTO). *Phytocoenosis*, 7 (N.S.), *Archivum Geobotanicum*, 4: 75–86.

Cieśliński S., Tobolewski Z. 1988. Porosty (Lichenes) Puszczy Białowieskiej i jej zachodniego przedpola [Lichens (Lichenes) of the Białowieża Forest and its western foreland]. *Phytocoenosis*, 1 (N.S.), *Supplementum Cartographiace Geobotanicae*, 1: 3–216.

Czyżewska K. 2003. Ocena zagrożenia bioty porostów Polski [The threat to lichens in Poland]. *Monographiae Botanicae*, 91: 241–249.

Czyżewska K., Cieśliński S. 2003. Porosty – wskaźniki niżowych lasów puszczańskich w Polsce [Lichens – Indicators of old-growth forests in Polish Lowland]. *Monographiae Botanicae*, 91: 223–239.

Dettki H., Esseen P.-A. 1998. Epiphytic macro lichens in managed and natural forest landscapes: a comparison at two spatial scales. *Ecography*, 21: 613–624.

Dróżdż T., Sarnowski P. 2004. Program Ochrony Przyrody. Nadleśnictwo Ciechanów, Obręb Ciechanów. Stan na 1.01.2004 r. Biuro Urządzania Lasu i Geodezji Leśnej Oddział w Olsztynie, Olsztyn: 1–163.

Fabiszewski J. 1968. Porosty Śnieżnika Kłodzkiego i Gór Bialskich. *Monographiae Botanicae*, 26: 1–155.

Fałtynowicz W. 1986. The dynamics and role of lichens in a managed *Cladonia*-Scotch pine forest (*Cladonio-Pinetum*). *Monographiae Botanicae*, 69: 3–96.

Fałtynowicz W. 2003. The lichens, lichenicolous and allied fungi of Poland. An annotated checklist. Kraków, W. Szafer Institute of Botany, PASc, p. 435. ISBN 83-89648-06-7.

Fałtynowicz W. 2006. Porosty w lasach Polski – znaczenie, zagrożenie, ochrona [Lichens in the Polish forests – importance, threat, conservation]. *Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej*, 8, 4 (14): 193–200.

Fedrowitz K., Kuusinen M., Snäll T. 2012. Metapopulation dynamics and future persistence of epiphytic cyanolichensin a European boreal forest ecosystem. *Journal of Applied Ecology*, 49 (2): 493–502.

Fritts H.C. 1961. An analysis of maximum summer temperatures inside and outside a forest. *Ecology*, 42 (2): 436–440.

Fritz Ö., Gustafsson L., Larsson K. 2008. Does forest continuity matter in conservation? – A study of epiphytic lichens and bryophytes in beech forest of southern Sweden. *Biological Conservation*, 141: 655–668.

Gu W.–D., Kuusinen M., Konttinen T., Hanski I. 2001. Spatial pattern in the occurrence of the lichen *Lobaria pulmonaria* to new localities and a review of the transplanting of lichens. *Windhalia*, 18: 57–64.

Hawksworth D.L., Coppins B.J., Rose F. 1974. Changes in the British lichen flora. In: Hawksworth D.L. (ed.) The changing flora and fauna of Britain, London & New York, Academic Press: 47–78.

Index Fungorum, 2013. CABI, CBS and Landcare Research. www.indexfungorum.org [5.03.2013].

Jankowski W. 2001. Naukowe podstawy i przyszłość korytarzy ekologicznych w Polsce. *Przegląd Przyrodniczy*, 12 (3–4): 41–53.

Jaroszewicz B. 2007. Różnorodność biologiczna lasów polskich. *Wszechświat*, 108 (4–6): 216–221.

Jüriado I., Liira J., Csencsics D., Widmer I, Adolf C., Kohv K., Scheidegger C. 2011. Dispersal ecology of the endangered woodland lichen *Lobaria pulmonaria* in managed hemiboreal forest landscape. *Biodiversity Conservation*, 20 (8): 1803–1819.

Kepel A. 2010. Natura 2000 w Polsce – Shadow List 2010. http://www.salamandra.org.pl/component/content/article/35-natura2000/374-natura-2000-w-polsce-shadow-list-2010.html?directory=175 [8.03.2013].

Kolanko K. 2009. Porosty rezerwatu przyrody „Starodrzew Szyndzielski" w Parku Krajobrazowym Puszczy Knyszyńskiej (północno-wschodnia Polska) [Lichens of the nature reserve of 'Starodrzew Szyndzielski' in Knyszyńska Forest Landscape Park (north-eastern Poland)]. *Parki Narodowe i Rezerwaty Przyrody*, 28 (2): 29–43.

Kondracki J. 2013. Geografia regionalna Polski. Warszawa, PWN, 444 pp. ISBN 9788301160227.

Kościelniak R. 2008. Znaczenie lasów o charakterze pierwotnym i naturalnym dla zachowania różnorodności gatunkowej porostów w Bieszczadach [The importance of primeval and natural forests for preservation of species diversity of lichens in the Bieszczady Mts.]. *Roczniki Bieszczadzkie*, 16: 6–76.

Kovach W.L. 2010. MVSP – A Multivariate Statistical Package for Windows, ver. 3.2. Pentraeth, Wales, U.K, Kovach Computing Services

Kubiak D. 2009. Porosty rezerwatu „Dziektarzewo" [Lichenes of the 'Dziektarzewo' naturere serve]. *Parki Narodowe i Rezerwaty Przyrody*, 28 (2): 45–55.

Kubiak D. 2011. Stan zachowania bioty porostów w rezerwatach „Dęby Napiwodzkie" i „Koniuszanka II" na Pojezierzu Olsztyńskim [State of preservation of the lichen biota in the Dęby Napiwodzkie and Koniuszanka II nature reserve in the Olsztyn Lakeland]. *Parki Narodowe i Rezerwaty Przyrody*, 30 (3–4): 27–39.

Kubiak D., Kukwa M. 2011. Chromatografia cienkowarstwowa (TLC) w lichenologii. In: Dynowska M., Ejdys E. (eds.) Mikologia laboratoryjna. Przygotowanie materiału badawczego i diagnostyka. Olsztyn, Wyd. UWM: 176–183. ISBN 978-83-7299-722-7.

Kubiak D., Sucharzewska E. 2012. Porosty – wskaźniki niżowych lasów puszczańskich w zespołach leśnych rezerwatu „Las Warmiński" (Nadleśnictwo Nowe Ramuki)

[Lichens – indicators of lowland old-growth forests in forest communities of the 'Las Warmiński' nature reserve (Nowe Ramuki Forest District)]. *Sylwan*, 156 (8): 627–636.

Kubiak D., Szczepkowski A. 2006. Lichens of the Rogów Forests of Warsaw Agricultural University (1). Arboretum, Popień and Zimna Woda reserves. *Annals of Warsaw University of Life Sciences – SGGW, Forestry and Wood Technology,* 60: 51–63.

Kubiak D., Szczepkowski A. 2012. Porosty Lasów Rogowskich SGGW (3): rezerwat „Doliska", zespół przyrodniczo-krajobrazowy „Dolina Mrogi" i uroczysko „Gutkowice" [Lichens of the Rogów Forests of Warsaw University of Life Sciences – SGGW (3): 'Doliska' reserve, 'Dolina Mrogi' nature-landscape complex and 'Gutkowice' forest part]. *Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej*, 14, 32 (3): 190–204.

Lesica P., McCune B., Cooper S.V., Hong W.S. 1991. Differences in lichen and bryophyte communities between old-growth and managed second growth forests in Swan Valley, Montana. *Canadian Journal of Botany*, 69: 1745–1755.

Liden M., Petterson M., Bergsten U., Lundmark T. 2004. Artificial dispersal of endangered epiphytic lichens: a tool for conservation in boreal forest landscapes. *Biological Conservation*, 118: 431–442.

Norris C., Hobson P., Ibisch P.L. 2012. Microclimate and vegetation function as indicators of forest thermodynamic efficiency. *Journal of Applied Ecology*, 49: 562–570.

Öckinger E., Niklasson M., Nilsson S.G. 2005. Is local distribution of the epiphytic lichen *Lobaria pulmonaria* limited by dispersal capacity or habitat quality? *Biodiversity Conservation*, 14: 759–773.

Otálora M.G, Martínez I., Belinchón R., Widmer I., Aragón G., Escudero A., Scheidegger C. 2011. Remnants fragments preserve genetic diversity of the old forest lichen *Lobaria pulmonaria* in a fragmented Mediterranean mountain forest. *Biodiversity Conservation*, 20: 1239–1254.

Perhans K., Appelgren L., Jonsson F., Nordin U., Soderstrom B., Gustafsson L. 2009. Retention patches as potential refugia for bryophytes and lichens in managed forest landscapes. *Biological Conservation*, 142: 1125–1133.

Pullin A.S. 2004. Biologiczne podstawy ochrony przyrody. Warszawa, Wyd. Nauk. PWN, p. 393. ISBN: 83-01-14283-9.

Scheidegger C., Frey B., Zoller S. 1995. Transplantation of symbiotic propagules and thallus fragments: methods for the conservation of threatened epiphytic lichen population. *Mitteilungen der Eidgenössischen Forschungsanstalt für Wald, Schnee und Landschaft*, 70 (1): 41–62.

Scheidegger C., Werth S. 2009. Conservation strategies for lichens: insights from population biology. *Fungal Biology Reviews*, 23: 55–66.

Selva S. 1994. Lichen diversity and stand continuity in the northern hardwoods and spruce-fir forests of northern New England and western New Brunswick. *Bryologist*, 97: 424–429.

Sillet S.C., McCune B. 1998. Survival and growth of cyanolichen transplants in Douglas-fir forest canopies. *Bryologist*, 101 (1): 20–31.

Sławski M. 2008. Wewnętrzna fragmentacja lasu i jej skutki przyrodnicze [Inner fragmentation of forest and its results for nature]. *Studia i Materiały Centrum Edukacji Przyrodniczo-Leśnej*, 10, 3 (19): 55–60.

Smith C.W., Aptroot A., Coppins B.J., Fletcher A., Gilbert O.L., James P.W., Wolseley P.A. (eds.) 2009. The lichens of Great Britain and Ireland. London, British Lichen Society, p. 1046. ISBN: 9780954041885.

Young A.G., Clarke G.M. 2000. Genetics, demography and viability of fragmented populations. Cambridge University Press, p. 438. ISBN: 9780521794213.

Werth S., Gugerli F., Holderegger R., Wagner H.H., Csencics D., Scheidegger C. 2007. Landscape-level gene flow in *Lobaria pulmonaria*, an epiphytic lichen. *Molecular Ecology*, 16: 2807–2815.

Werth S. 2005. Dispersal and persistence of an epiphytic lichen in a dynamic pasture-woodland landscape. Ph.D. thesis, University of Berne. https://www.eeb.ucla.edu/Faculty/Sork/Werth/pdf/PhD_Thesis_SilkeWerth.pdf [3.03.2013].

Wieczorek A.2009. Porosty rezerwatów Szczecińskiego Parku Krajobrazowego [Lichens of nature reserves of the Szczecin Landscape Park]. *Zeszyty Naukowe Uniwersytetu Szczecińskiego*, 581, *Acta Biologica*, 16: 155–165.

Translated by: Martyna Olszowska