Acta Biol. Univ. Daugavp. 18 (2) 2018
ISSN 1407 - 8953

BRYOPHYTE AND LICHEN DISTRIBUTION IN URBAN FORESTS OF RIGA CITY LIMITS

Anna Mežaka, Ligita Liepiņa, Līga Strazdiņa, Evita Oļehnoviča, Alfons Piterāns

Mežaka A., Liepiņa L., Strazdiņa L., Oļehnoviča E., Piterāns A. 2018. Bryophyte and lichen distribution in urban forests of Riga city limits. *Acta Biol. Univ. Daugavp., 18 (2): 255 – 271.*

Forests are among the major contributors of biodiversity in Riga city limits, representing potential habitats and substrates for bryophytes and lichens. Bryophytes and lichens were studied in 82 forest stands from seven stand types (dry *Pinus sylvestris* forest, wet *Pinus sylvestris* forest, wet deciduous forest, dry deciduous forest, nemoral forest, dry mixed forest, wet mixed forest) of Riga city limits. The random walk procedure was applied and bryophyte and lichen data were analyzed in relation to forest stand age, area, type and heterogeneity. In total 99 bryophyte and 60 lichen species were found, from which 27 bryophyte and 28 lichen species were new to Riga city limits. Bryophyte community structure was mostly explained by forest stand age and are. Lichen community structure was explained by forest stand age, area and heterogeneity. The results are important in long-term nature conservation planning in urban forests.

Key words: lichens, bryophytes, urban forest, forest stand.

Anna Mežaka. Insitute of Life Sciences and Technologies, Daugavpils University, Parades street 1a, Daugavpils, Latvia, E-mail:bryo82@gmail.com.
Ligita Liepiņa. Academic Department, University of Latvia, Raiņa Boulevard 19, Riga, Latvia, E-mail:ligita.liepina@lu.lv
Līga Strazdiņa. LU Botanical garden, Kandavas street 2, Riga, Latvia, E-mail:liga.strazdins@gmail.com
Evita Oļehnoviča. Latvian Botanical Society, Berģu street 147, Riga, Latvia, E-mail: ewy14@inbox.lv
Alfons Piterāns. Department of Botany and Ecology, University of Latvia, Kronvalda Boulevard 4, Riga, Latvia, E-mail: apiteran@lanet.lv

INTRODUCTION

Urban territories are major producers of greenhouse gases and air pollutants, causing health problems for people and the environment (Wu 2014). Fragmentation and pollution (Hauck 2011) are two of the main negative environmental impacts on urban forests. Biodiversity in urban forests represents a critical ecosystem service in sustaining human health and environmental quality (Alvey 2006). Urban green spaces provide various ecological, environmental, economic and socio-cultural benefits (Wu 2014).

Historically, forests within Riga city limits were used for building material, firewood and cattle grazing. No forest management legislation was applied inside city limits until 1824, when "Laws concerning the forest " came out, serving as a basis for future forest management inside city limits (SIA Rīgas meži 2013).

Riga traditionally has been called a City of Gardens and Parks (Emsis 1980) and within city limits, there are various semi-natural forest types. Forests are among the most important areas for biodiversity conservation in city limits. The total forest cover in Riga city limits is 5,500 ha (Estonian, Latvian & Lithuanian Environment 2013) and dry coniferous forests of *Pinus sylvestris* have been and will likely continue to be the most common forest type (Rīgas meži 2014). Bryophytes and lichens are important components in forest ecosystems, and they are also indicators of valuable habitats with high conservation value (Nordén et al. 2007).

Currently, published information exists for 86 bryophyte species (Mikutowicz 1908-1913, Malta & Strautmanis 1926, Malta 1927, 1930, Āboliņa 1968, 2000, Jakovičs 2011, 2013), and 43 lichen species (Piterāns 1965, 1981, 1998, 2000, 2001, Piterāns & Bērziņa 1990) found in the forests within Riga city limits. Most of the previous studies have been devoted to different habitats such as grasslands and parks, while forests have been less studied.

Previous studies about lichens and bryophytes in different European cities showed that sources of pollutants mainly are vehicle emissions (Larsen et al. 2007, Marmor & Randlane 2007, Motiejūnaitė 2009, Sujetuviene & Sliumpaite 2013), increasing stress of recreation (Motiejūnaitė 2009) and factories (Dymytrova 2009). Differencies were found in bryophyte and lichen richness among European urban areas in cities. For instance, 65 lichen and 20 bryophyte species were found on trees in Kyiv city (Dymytrova 2009), 72 lichen species were recorded on various substrates in two Regional parks in Vilnius area (Motiejūnaitė 2009). Larsen et al. (2007) recorded 64 lichen and four bryophyte species on *Quercus* sp. in London, Marmor & Randlane (2009) found 45 lichen species on *Pinus sylvestris* in Tallinn, but these studies were conducted in different habitats as parks, grasslands, forests.

Forest habitat type is an important driver in cryptogam distribution (Cieśliński et al. 1996), where the forest stand area is a relevant attribute for species population long-term existence (Hanski & Ovaskainen 2001; Baldwin & Bradfield 2007) and for bryophyte and lichen diversity (Gignac & Dale 2005). Forest stand age shows a positive correlation with epiphytic lichen species richness (Hedenås & Ericsson 2000, Johansson et al. 2007), and mature trees are significant substrates for epiphytic lichens in managed forest landscape (Hauck et al. 2013). Also, tree species diversity has an important role in bryophyte and lichen distribution in forests (Barkman 1958, Jüriado et al. 2009).

The aim of the present study was to characterize bryophyte and lichen distribution in forests of Riga city limits in relation to forest stand characteristics.

MATERIALS AND METHODS

Study areas

The study areas were selected from Riga forest inventory database and forest maps (VMD 2013) based on criteria – territories with different forest types and geographical locations in Riga, where information about lichens and bryophytes is lacking. As a result, the data were collected in eight different areas in forests of Riga – Bolderāja - Daugavgrīva, Beberbeķi - Ziepniekalns, Berģi, Jaunciems, Jugla - Biķernieki, Mangaļsala, Mežaparks, Vecāķi - Trīsciems (Fig. 1). In total 82 forest stands were studied in these areas. The annual average rainfall in Riga is 700–720 mm, the average temperature in January - 4.7^{o} C, average temperature in July + 16.9^{o} C (LVĢM 2013).

The study was conducted in seven forest types – dry *Pinus sylvestris* forest, wet *Pinus sylvestris* forest, wet deciduous forest, dry deciduous forest, broad-leaved (nemoral) forest, dry mixed forest, wet mixed forest (Table 1).

The most common was dry *Pinus sylvestris* forest (53 forest stands). The age of studied forest stands varied between 10 and 220 years and the area varied between 0.25 and 24.60 ha (Table 1) of these forest stands. The oldest forest stands were found in dry *Pinus sylvestris* forest, but the largest forest stands represented both dry *Pinus sylvestris* forest and wet deciduous forest stands (Fig. 2, Table 1). Dry mixed forests showed the highest heterogeneity (number of tree species per forest stand) (Table 1).

Field work

The data about bryophyte and lichen occurrence were collected by four people using a modified random walk procedure according to Kent & Coker (1992) in each forest stand. The selected method is appropriate in biodiversity studies for the purpose to prepare complete or close to complete species list in the studied area. Most species were identified in the field, but samples of some species were collected for identification

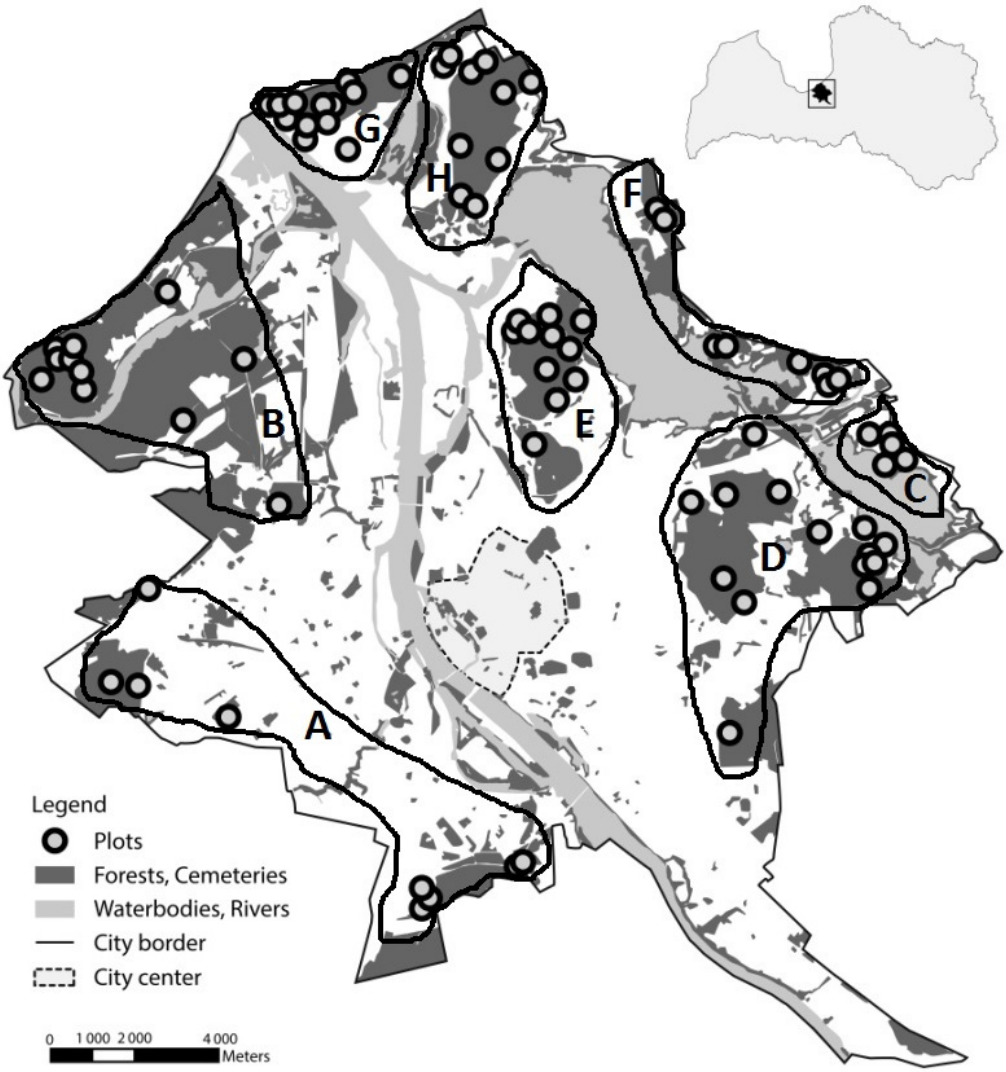

Fig. 1. Studied areas in Riga city limits. Each plot represents one forest stand. A- Beberbeķi - Ziepniekalns, B- Bolderāja - Daugavgrīva, C- Berģi, D- Jugla - Biķernieki, E - Mežaparks, F - Jaunciems, G - Mangaļsala, H – Vecāķi - Trīsciems.

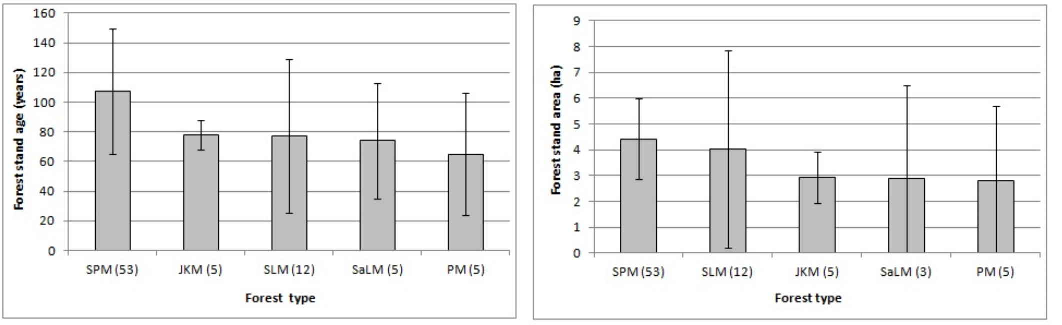

Fig. 2. Studied forest stand age and area among forest types. Average values and standart deviations are given. The number of forest stands in brackets. Forest types as follows – SPM – dry *Pinus sylvestris* forest, SaLM – dry deciduous forest, JKM – dry mixed forest, SLM – wet deciduous forest, PM – broad-leaved (nemoral) forest. Wet mixed forest and wet *Pinus sylvestris* forest were removed from graphs as these types represent only one forest stand each.

Table 1. Characteristics of studied forests in Riga city limits forests. Number of forest stands in brackets of forest type column

Forest type	**Tree species**	**Forest stand area (ha, average in brackets)**	**Forest stand age (years, average in brackets)**
Dry deciduous forest (5)	*Alnus incana, Alnus glutinosa, Betula pendula, Pinus sylvestris*	0.70-8.50 (4.29)	50-140 (110)
Dry *Pinus sylvestris* forest (53)	*Pinus sylvestris, Tilia cordata, Betula pendula, Sorbus aucuparia, Acer platanoides*	0.30-24.60 (5.03)	10-220 (107,17)
Wet deciduous forest (12)	*Betula pendula, Pinus sylvestris, Alnus glutinosa, Alnus incana, Picea abies, Populus tremula*	0.25-11.10 (3.79)	30-150 (77.27)
Wet mixed forest (1)	*Pinus sylvestris, Betula pendula, Alnus glutinosa, Alnus incana*	1.73	60
Wet *Pinus sylvestris* forest (1)	*Pinus sylvestris, Betula pubescens*	7.10	100
Dry mixed forest (5)	*Populus tremula, Populus sp., Ulmus glabra, Betula pendula, Pinus sylvestris, Ulmus glabra, Alnus glutinosa*	0.81-4.90 (2.93)	50-150 (60)
Nemoral forest (5)	*Tilia cordata, Quercus robur, Ulmus glabra, Ulmus laevis*	1.00-3.50 (2.81)	60-100 (70)

at the laboratory.

One forest stand was one sample plot and unit in the present study. Species were recorded on different substrates (living tree stem, dead wood, soil, stone, artificial substrates (cement)) until species richness was not changing anymore in the particular forest stand in each walk.

Laboratory work

Collected bryophyte and lichen samples were identified in a laboratory using stereomicroscope and microscope. Paraphenylenediamine, Chlorox (C), potassium chloride and ethylene were used for lichen identification. In addition, Thin Layer Chromatography (with solvent systems A, B, C) were used for *Lepraria* species identification (Orange et al. 2001) at Rezekne Academy of Technologies in 2015. The scientific names for bryophytes, lichens, and vascular plants follow Āboliņa et al. (2015), GBIF (2015), Grolle & Long (2000), Hill et al. (2006), Piterāns (2001), Priedītis (2014), Soderström et al. (2016). Names of bryophyte and lichen authors follow Brummit & Powell (1992).

Data analysis

The data were analyzed using Canonical Correspondence Analysis (CCA) in PCord (Version 5) program. Data from 82 forest stands with 56 bryophyte and 77 forest stands with 26 lichen species (species with 1-3 records were removed from the analysis as not to decrease occurrence by chance) were analyzed. Our sampling unit was a forest stand.

The bryophyte and lichen species occurrence were analyzed with CCA in relation to forest stand area, forest stand age, forest type and number of tree species in overstorey (heterogeneity). Only significant factors ($p<0.05$) were noted in ordination. As our sampled forest stands were heterogenous and not homogenous, we could apply multivariate analysis to our data (Zdenka & Chytrý 2006).

RESULTS

Species richness

In total 99 bryophyte and 60 lichen species were found in studied forest stands, among them, 27 bryophyte species, and 28 lichen species were new to Riga (Appendix). The highest total (134), moss (72), liverwort (10) and lichen (52) species richness was found in dry *Pinus sylvestris* forests, followed by wet deciduous forest (in total 76 species – 50 moss species, seven liverwort species, and 19 lichen species; Appendix 1). The most common bryophyte species were *Hypnum cupressiforme, Pleurozium schreberi, Dicranum scoparium, Hylocomium splendens, Plagiomnium affine, Lophocolea heterophylla*, most common lichen species were *Hypogymnia physodes, Chaenotheca ferruginea* and *Lepraria incana*. Four bryophyte species (*Homalia trichomanoides, Leucobryum glaucum, Nowellia curvifolia, Ulota crispa* and one lichen species (*Graphis scripta*) were Woodland Key Habitat (WKH) indicator species (Eĸ et al. 2002). *Leucobryum glaucum,* genus *Sphagnum* and *Cladonia* subgenus *Cladina* species are included in the Council Directive on the conservation of natural habitats and wild fauna and flora, Annex V (EU 1992).

Bryophyte and lichen communities in relation to forest stand characteristics

The bryophyte and lichen community structure, according to CCA, can be explained mostly by forest stand age, area and heterogeneity (Fig. 3, Fig. 4). Axis 1 of bryophyte species ordination could be partly explained by forest stand age ($r=-0.46$), where *Brachythecium albicans, Plagiomnium ellipticum, Polytrichum formosum, Mnium hornum* were characteristic in older forest stands, but *Polytrichum piliferum, Platygyrium repens* were in younger forest stands (Fig. 3).

Axis 2 of bryophyte species ordination was correlated with forest stand area ($r=-0.52$) and weakly with heterogeneity ($r=0.08$). *Sanionia uncinata, Calliergonella cuspidata, Climacium dendroides, Calliergon cordifolium* were

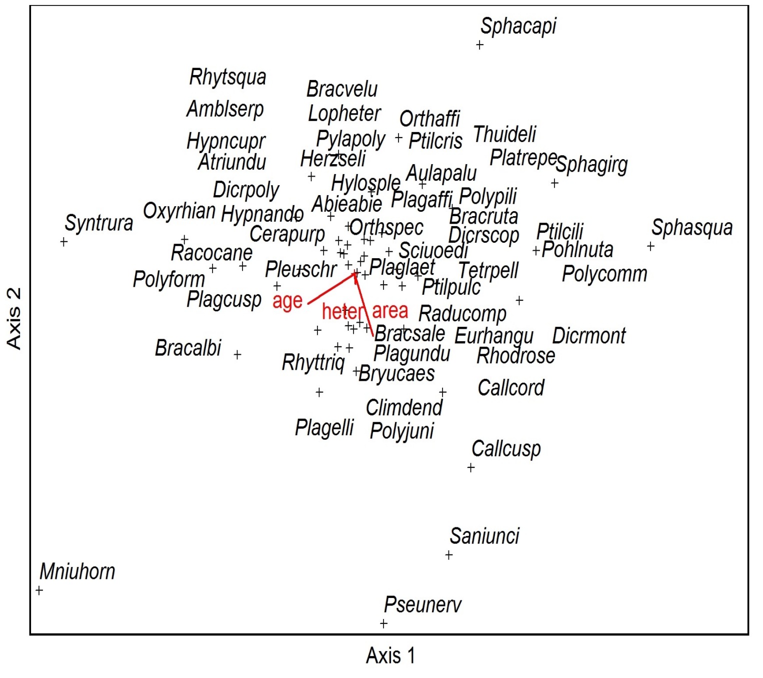

Fig. 3. Bryophyte species CCA ordination in relation to forest stand age (age), area and heterogeneity. Age was correlated to Axis 1 (r=-0.46). Area (r=-0.52) and heterogeneity (r=0.08) were correlated with Axis 2. Species abbreviations in Appendix.

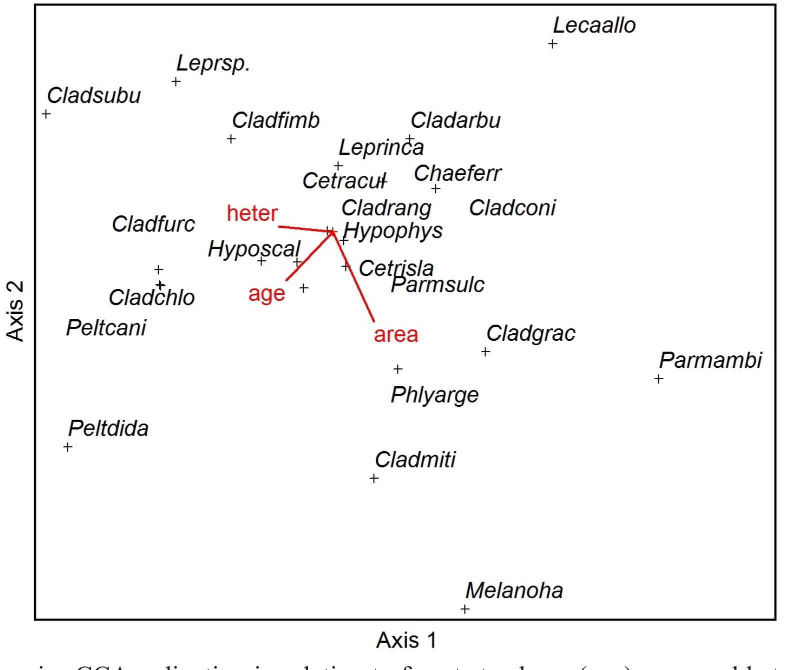

Fig.4. Lichen species CCA ordination in relation to forest stand age (age), area and heterogeneity. Heterogeneity (r=-0.51) was correlated with Axis 1. Age (r=-0.55) and area (r=-0.92) were correlated with Axis 2. Species abbreviations in Appendix.

characteristic in larger forest stands, while *Rhytidiadelphus squarrosus, Amblystegium serpens* were in smaller forest stands (Fig. 3). Axis 1 of lichen species ordination could be partly explained by heterogeneity (r=-0.51). Lichens *Cladonia subulata, Cladonia furcata* were related with heterogeneity positively, but *Cladonia coniocraea, Parmeliopsis ambigua* negatively (Fig. 4).

Axis 2 in lichen species ordination was correlated with forest stand age (r=- 0.55) and forest stand area (r=-0.92). *Peltigera didactyla* and *Peltigera canina* were positively related, but *Cladonia arbuscula* negatively with forest stand age (Fig. 4). *Phlyctis argena* and *Cladonia mitis* were positively related to forest stand area, while *Lepraria* sp., *Cladonia subulata* negatively.

DISCUSSION

The discovery of many new bryophyte and lichen species during the present study, in comparison to previous studies, might be explained that past studies were devoted mostly to separate different habitats or geographical parts, but not specifically to Riga urban forests.

Furthermore, forests around Riga are urbanized and homogenized with high human pressure representing similar species composition among forest types in contrast to forests in more remote areas. We did not study the influence of air pollution on lichen and bryophyte distribution, but based on studies in other urban areas in Europe; Rome (Munzi et al. 2006), Wrocław (Fudali 2012), Ferrara (Gerdol et al. 2014), pollution have significant influence on cryptogam occurrence. Therefore studies in Tallinn (Marmor & Randlane 2007), London (Larsen et al. 2007) and Vilnius (Motiejūnaitė 2009) emphasized the traffic induced air pollution influence on bryophyte and lichen distribution and we think, that similar trend could also be found in the Riga. The highest bryophyte species richness (82 species) in dry *Pinus sylvestris* forest and lower in other forest types as in wet deciduous forest (57 species) might be explained by differences in number of forest stand replications among forest types (Fig. 2). However, forests in urban area may not represent high species richness found in natural or semi-natural conditions.

The deciduous tree occurrence in coniferous forest as well as coniferous tree presence in deciduous forest increase the habitat heterogeneity for potential epiphytes. Meier et al. (2005) found, that lichen species diversity is highly related to tree species diversity in forest stands. Heterogeneity in the present study could be related to tree bark pH since deciduous trees have higher pH in contrast to coniferous trees (Barkman 1958). Doering & Coxson (2010) noted, that deciduous trees among coniferous forests ensure dispersal corridors for the epiphytic lichens. Heterogeneity also significantly influenced bryophyte and lichen diversity in a study by Gignac & Dale (2005). However, we find a weak relationship between heterogeneity and bryophyte species composition. Bryophyte priorities might be other conditions in forest stand e.g. substrate longevity. Most of the forest stands in this study were dry *Pinus sylvestris* forests, where is low bryophyte species richness and diversity in contrast to lichens.

Leucobryum glaucum and *Nowellia curvifolia* are WKH indicator species (Ek et al. 2002), therefore they are more common in older forests. But several species like *Platygyrium repens* and *Polytrichum piliferum* are common also in younger forest stands as found in present study. *Phlyctis argena* and *Cladonia chlorophaea* were positively related with forest stand age in present study and also in study by Johansson et al. (2007). However, *Lecanora allophana* was negatively related with forest stand age in the present study, but positively in study by Johansson et al. (2007). The present study was characterized by dry coniferous forests and lack of *Fraxinus excelsior*, while Johansson et al. (2007) were studied forest stands with *Fraxinus excelsior* in semi-natural conditions. In addition, urban area as Riga, presents also other accidental and unpredictable conditions and unstable ecosystem.

Our results confirm, that forest stand age is an important factor influencing the presence of different organism groups (Meier et al. 2005) also in urban forests. It was also found to be important for dead wood availability in coniferous forests and bryophyte diversity in Estonia (Rajandu et al. 2009).

Forest stands in Riga have been influenced by management activities in a long-term (SIA Rīgas meži 2013). However, forest habitats ensuring bryophyte and lichen richness and composition still exist. Forest stands with different tree species and especially older stands should be conserved in a future. However, bryophyte and lichen composition varied between forest stands with different stand age (Fig. 3, Fig. 4.). Forest stands representing trees with different age should be conserved ensuring forest ecosystem integrity and species long-term existence. Tikkanen et al. (2006) also suggest to conserve young as well as old-growth forests for long-term conservation of different organism groups.

Forest stand area was significant also in the study by Alvey (2006), where species richness was correlated with forest patch area. The larger forest patch ensures more space for long-term existence of epiphyte species if this forest patch will be unaffected by forest cuttings.

Urban and suburban areas may have high biodiversity and urban foresters as well as city planners may preserve and promote biodiversity, incorporating a more ecological perspective into their management plans (Alvey 2006), contributing also to the mitigation of global change (Niemelä 2014). The results of the present study are important in a long-term nature conservation planning of urban forest ecosystems.

The present paper showed the general trends in bryophyte and lichen distribution in forests of Riga. More detailed studies, where bryophyte and lichen cover estimates and substrate parameters could be included, are needed. We suggest to organize bryological and lichenological studies, including monitoring sites, also in other habitats of urban areas.

ACKNOWLEDGEMENTS

The present study was financially supported by Rīgas Vides aizsardzības fonds (Riga city council) in cooperation with "Rīgas meži" Ltd. (project nr. L-2833-ZR-S-0900).

Thanks is given to Austra Āboliņa for valuable comments on species identification. We are grateful to State Forest Service and Uvis Suško for maps and Vita Rudzīte, Uldis Gaiss for consultations and discussions about forests in Riga city limits.

REFERENCES

Abolina A. 1968. Listostebelnie mhi Latviskoi SSR. Rīga. (In Russian).

Āboliņa A. 2000. *Vai Rīgā aug aknu sūnas*? – In: Tava labākā grāmata par Latviju. Enciklopēdija katrai ģimenei, 229–232.

Āboliņa A., Piterāns A., Bambe B. 2015. Latvijas ķērpji un sūnas. Taksonu saraksts. Salaspils. (*In Latvian*).

Alvey A. A. 2006. Promoting and preserving biodiversity in the urban forest. *Urban Forestry and Urban Greening*, 5: 195–201.

Baldwin L. K., Bradfield G. E. 2007. Bryophyte responses to fragmentation in temperate coastal rainforests: A functional group approach. *Biological Conservation*, 136: 408–422.

Barkman J. J. 1958. Phytosociology and ecology of cryptogamic epiphytes. – Assen.

Brummit P.K., Powell C.E. 1992. Authors of plant names. Kew.

Cieśliński S., Czyżewska K., Klama H.,

Żarnowiec J. 1996. Part three. Use of forest environment by cryptogamous plants. XIII. EPIPHYTES AND EPIPHYTISM. *Phytocoenosis*, 8: 15–35.

Doering M., Coxson D. 2010. Riparian alder ecosystems as epiphytic lichen refugia in sub-boreal spruce forests of British Columbia. *Botany*, 88: 144–157.

Dymytrova L. 2009. Epiphytic lichens and bryophytes as indicators of air pollution in Kyiv city (Ukraine). *Folia Cryptogamica Estonica,* 46: 33-44.

Ek T., Suško U., Auziņš R. 2002. Inventory of woodland key habitats. Riga.

Emsis I. 1980. Rīgas pilsētas meži un to apsaimniekošana. Rīga. (*In Latvian*).

Estonian, Latvian & Lithuanian Environment 2013. Strategical environmental evaluation of Riga territory planning 2006 -2018. Environmental report. Rīga.

EU 1992 (Council Directive on the conservation of natural habitats and of wild fauna and flora 92/43/EEC 1992). Annex V. Official Journal of European Communities.

Fudali E. 2012. Recent tendencies in distribution of epiphytic bryophytes in urban areas: a Wrocław case study (South-west Poland). *Polish Botanical Journal*, 57(1): 231-141.

Gerdol R., Marchesini R., Iacumin P., Brancaleoni L. 2014. Monitoring temporal trends of air pollution in an urban area using mosses and lichens as biomonitors. *Chemosphere,* 108: 388-395.

Gignac L. D., Dale M. R. T. 2005. Effects of Fragment Size and Habitat Heterogeneity on Cryptogam Diversity in the Low-boreal Forest of Western Canada. *The Bryologist,* 108(1): 50–66.

Global Biodiversity information facility 2015 (GBIF 2015). http://www.gbif.org/species, accessed in 7th of December 2015.

Grolle R., Long D. 2000. An annotated check-list of the Hepaticae and Anthocerotae of Europe and Macaronesia. *Journal of Bryology*, 22: 103–140.

Hanski I., Ovaskainen O. 2001. Extinction debt at extinction threshold. *Conservation Biology,* 16(3): 666–673.

Hauck M., de Bruyn U., Leuschner C. 2013. Dramatic diversity losses in epiphytic lichens in temperate broad-leaved forests during the last 150 years. *Biological Conservation*, 157: 136–145.

Hauck, M. 2011. Site factors controlling epiphytic lichen abundance in northern coniferous forests. *Flora,* 206: 81–90.

Hedenås H., Ericsson L. 2000. Epiphytic macrolichens as conservation indicators: successional sequence in *Populus tremula* stands. *Biological Conservation*, 93: 43–53.

Hill M. O., Bell N., Bruggeman-Nannenga M. A., Brugue´s M., Cano M. J., Enroth J., Flatberg K. I., Frahm J., Gallego M. T., Garilleti R., Guerra J., Hedenås L., Holyoak D. T., Gyvonen J., Ignatov M. S., Lara F., Mazimpaka V., Munoz J., Soderstrom L. 2006. An annotated checklist of the mosses of Europe and Macaronesia. Bryological monograph. *Journal of Bryology*, 28: 198–267.

Jakovičs A. 2013. Mežaparks. Rīgas ekotūrisma ceļvedis. Rīga. (*In Latvian*).

Jakovičs A. 2011. Šmerlis. Rīgas ekotūrisma ceļvedis. Rīga. (*In Latvian*).

Johansson P., Rydin H., Thor G. 2007. Tree age relationships with epiphytic lichen diversity and lichen life history traits on ash in southern Sweden. *Ecoscience*, 14 (1): 81–91.

Jüriado I., Liira J., Paal J. 2009. Diversity of epiphytic lichens in boreo-nemoral forests on the North-Estonian limestone escarpment: the effect of tree level factors and local environmental conditions. *The Lichenologist*, 41 (1): 81–96.

Kent M., Coker P. 1992. Vegetation description and analysis. A practical Approach. London.

Larsen R.S., Bell J.N.B., James P.W., Chimonides P.J., Rumsey F.J., Tremper A., Purvis O.W. 2007. Lichen and bryophyte distribution on oak in London in relation to air pollution and bark acidity. Environmental pollution 146: 332–340.

LVĢMA 2013. Latvijas vides ģeoloģijas un meteoroloģijas centrs. http://www.meteo.lv/lapas/par-centru/par-centru-1?id=1469&nid=327. (*In Latvian*).

Malta N. 1927. Übersicht der Moosflora des Ostbaltischen Gebietes II Laubmoose. *Acta Horti Botanici Universitatis Latviensis,* 2 (1): 19–36.

Malta N. 1930. Übersicht der Moosflora des Ostbaltischen Gebietes II Laubmoose (Andreaeales et Bryales). *Acta Horti Botanici Universitatis Latviensis,* 5(1/3): 75–104.

Malta N., Strautmanis J. 1926. Übersicht der Moosflora des Ostbaltischen Gebietes I. *Acta Horti Botanici Universitatis Latviensis,* 1: 116–142.

Marmor L., Randlane T. 2007. Effects of road traffic on bark pH and epiphytic lichens in *Tallinn. Folia Cryptogamica Estonica*, 43: 23-37.

Meier E., Paal J., Liira J., Jüriado I. 2005. Influence of tree stand age and management on the species diversity in Estonian eutrophic alvar and boreo-nemoral Pinus sylvestris forests. *Scandinavian Journal of Forest Research,* 20 (6): 134–144.

Mikutowicz J. 1908-1913. Bryotheca Baltica. Sammlung ostbaltischer Moose. Bogen. – Rīga.

Motiejūnaitė J. 2009. Lichens and allied fungi of two regional parks in Vilnius area (Lithuania). *Acta Mycologica*, 44(2): 185-199.

Munzi S., Ravera S., Caneva G. 2006. Epiphytic lichens as indicators of environmental quality in Rome. *Environmental Pollutio*n, 146: 350-358.

Nordén B., Paltto H., Götmark F., Wallin K. 2007. Indicators of biodiversity, what do they indicate? – Lessons for conservation of cryptogams in oak-rich forest. *Biological Conservation*, 135: 369–379.

Niemelä J. 2014. Ecology of urban green spaces. The way forward in answering major research questions. *Landscape and Urban Planning*, 125: 298-303.

Orange A., James P. W., White F. J. 2001. Microchemical methods for the identification of lichens. *British Lichen Society*, 97: 69–79.

Piterans A. 1965. Rasprostranjenie lishainikov v Rige. In: Problems in Mycology and Lichenology. Akademiia Nauk Estonskoi SSR: 191–194. Tartu.

Piterans A. 1968. The influence of superphosphate factory on lichen development. In: Materials III of Transcaucasian Conference about Cryptogams: Tbilisi. Pp 251 – 253. (*in Russian*).

Piterāns A. 1965. Gaisa tīrības bioindikatori. Zinātne un tehnika, 12: 43–44. (*In Latvian*).

Piterāns A. 1981. Ķērpji kā vides bioindikatori. In: Latvijas PSR floras aizsardzības aktuālās problēmas. Rīga. Pp 55-62. (*In Latvian*).

Piterāns A. 1998. Lichens in Riga city. In: Tava labākā grāmata par Latviju. Enciklopēdija katrai ģimenei. Rīga.Pp 230–233. (*In Latvian*).

Piterāns A. 2000. Lichens of cities. In: Dabas un vēstures kalendārs. Riga. Pp 166–168. (*In Latvian*).

Piterāns A. 2001. Latvijas ķērpju konspekts. In: Latvijas Veģetācija 3. Riga. Pp 5–46.

Piterāns A., Bērziņa S. 1990. Rīgas pilsētas lihenoindikācija. – Latvijas ekoloģija, 2: 61–67. (*In Latvian*).

Priedītis N. 2014. Latvijas augi. Rīga. (*In Latvian*).

Rajandu E., Kikas K., Paal J. 2009. Bryophytes and decaying wood in Hepatica site-type boreo-nemoral *Pinus sylvestris* forests in Southern Estonia. Forest Ecology and Management, 257: 994–1003.

SIA Rīgas meži 2013. Meža apsaimniekošanas plāns. Kopsavilkums. Rīga. (*In Latvian*).

Rīgas meži, 2014: Statistika. http://www.rigasmezi.lv/lv/mezi/statistika/. Rīga. (*In Latvian*).

Soderström L., Hagborg A., von Konrat M., Bartholomew-Began S., Bell D., Briscoe L., Brown E., Cargill D.C., Costa D. P., Crandall-Stotler B.J., Cooper E.D., Dauphin G., Engel J.J., Feldberg K., Glenny D., Gradstein S. R., He X., Heinrichs J., Hentschel J., Ilkiu-Borges A.L., Katagiri T., Konstantinova N. A., Larraín J., Long D.G., Nebel M., Pócs T., Puche F., Reiner-Drehwald E., Renner M.A.M., Sass-Gyarmati A., Schäfer-Verwimp A., Segarra Moragues J.G., Stotler R. E., Sukkharak P., Barbara M. Thiers B. M. ,Uribe J., Váňa J., Villarreal J.C., Wigginton M., Zhang L., Zhu R. L. 2016. World checklist of hornworts and liverworts. Phytokeys, 59: 1-828.

Sujetuviene G., Sliumpaite I. 2013. Response of *Evernia prunastri* transplanted to an urban area in central Lithuania. *Atmospheric Pollution Research*, 4: 222-228.

Tikkanen O.-P., Martikainen P., Hyvärinen E., Junninen K., Kouki J. 2006. Red-listed boreal forest species of Finland: associations with forest structure, tree species and decaying wood. *Annales Zoologici Fennici*, 43: 373–383.

VMD 2013. *Valsts meža dienesta datu bāze* http://karte.vmd.gov.lv:7777/vmdgis/main.jsp#. (*In Latvian*).

Wu J. 2014. Urban ecology and sustainability: The state-of-the-science and future directions. *Landscape and urban planning*, 125: 209-221.

Zdenka O., Chytrý M. 2006. Effects of plot size on the ordination of vegetation smaples. *Journal of Vegetation Science,* 17:465-472.

Received: 29.11.2018.
Accepted: 10.12.2018.

APPENDIX

Bryophyte and lichen species list recorded in forests of Riga city limits. Abbreviations and symbols: * – species new to Riga City limits; Abbrev –abbreviation for species used in CCA ordination; Forest type: 1 – dry *Pinus sylvestris* forest, 2 – wet *Pinus sylvestris* forest, 3 – wet deciduous forest, 4 – dry deciduous forest, 5 – nemoral forest, 6 – dry mixed forest, 7 – wet mixed forest (numbers in brackets – number of forest stands). T – total number of species occurrences. Numbers show records of each species in each area and forest type

Species	**Abbrev**	**Forest type**							**T**
		1 (53)	**2 (1)**	**3 (12)**	**4 (5)**	**5 (5)**	**6 (5)**	**7 (1)**	
MOSSES									
Abietinella abietina (Hedw.) M.Fleisch.	*Abieabie*	12	0	0	1	0	1	0	14
Amblystegium serpens (Hedw.) Schimp.	*Amblserp*	6	0	1	0	3	2	0	12
Atrichum undulatum (Hedw.) P.Beauv.	*Atriundu*	3	0	1	2	1	1	1	9
Aulacomnium androgynum (Hedw.) Schwägr.		2	0	0	0	0	1	0	3
Aulacomnium palustre (Hedw.) Schwägr.*	*Aulapalu*	3	0	0	1	0	0	1	5
Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen*	*Bracvelu*	5	0	0	0	1	2	0	8
Brachythecium albicans (Hedw.) Schimp.	*Bracalbi*	8	0	1	1	0	0	0	10
Brachythecium rutabulum (Hedw.) Schimp.	*Bracruta*	11	0	6	1	4	2	0	24
Brachythecium salebrosum (Hoffm. ex F.Weber & D.Mohr) Schimp., nom. cons.	*Bracsale*	13	0	6	0	4	4	0	27
Bryum argenteum Hedw.		1	0	0	0	0	0	0	1
Bryum caespiticium Hedw.	*Bryucaes*	5	0	1	0	0	0	0	6
Bryum pseudotriquetrum (Hedw.) P. Gaertn. et al.*		0	0	1	1	0	0	0	2
Buxbaumia aphylla Hedw.		2	0	0	0	0	0	0	2
Callicladium haldanianum (Grev.) H.A.Crum		1	0	0	1	0	0	0	2
Calliergon cordifolium (Hedw.) Kindb.	*Callcord*	1	0	4	1	0	1	0	7
Calliergonella cuspidata (Hedw.) Loeske	*Callcusp*	1	0	5	1	2	0	0	9
Ceratodon purpureus (Hedw.) Brid.	*Cerapurp*	19	0	2	1	0	0	0	22
Cirriphyllum piliferum (Hedw.) Grout		2	0	0	0	0	0	0	2
Climacium dendroides (Hedw.) F.Weber. & D.Mohr	*Climdend*	20	0	6	2	1	3	0	32
Dicranella heteromalla (Hedw.) Schimp.*		1	0	0	0	0	0	0	1
Dicranum montanum Hedw.	*Dicrmont*	9	1	2	1	0	3	0	16
Dicranum polysetum Sw. ex anon.	*Dicrpoly*	19	1	1	1	0	0	1	23
Dicranum scoparium Hedw.	*Dicrscop*	41	1	5	3	3	2	1	56
Dicranum spurium Hedw.*		1	0	0	0	0	0	0	1
Didymodon rigidulus Hedw.*		1	0	0	0	0	0	0	1

Species	Abbrev	Forest type							T
		1 (53)	**2 (1)**	**3 (12)**	**4 (5)**	**5 (5)**	**6 (5)**	**7 (1)**	
Encalypta streptocarpa Hedw.		1	0	0	0	0	0	0	1
Eurhynchium angustirete (Broth.) T.J.Kop.	*Eurhangu*	7	0	1	1	1	1	1	12
Eurhynchium striatum (Hedw.) Schimp.*		2	0	1	0	0	0	0	3
Fissidens taxifolius Hedw.*		0	0	1	0	0	0	0	1
Funaria hygrometrica Hedw.		2	0	0	0	1	0	0	3
Grimmia pulvinata (Hedw.) Sm.*		1	0	0	0	0	0	0	1
Herzogiella seligeri (Brid.) Z.Iwats.*	*Herzseli*	13	0	2	3	1	1	0	20
Homalia trichomanoides (Hedw.) Brid.		0	0	1	0	0	1	0	2
Hygroamblystegium varium (Hedw.) Mönk.*		0	0	1	0	0	0	0	1
Hylocomium splendens (Hedw.) Schimp.	*Hylosple*	37	1	3	2	0	5	2	50
Hypnum andoi A.J.E Sm.*	*Hypnando*	6	0	2	2	2	1	0	13
Hypnum cupressiforme Hedw.	*Hypncupr*	41	0	8	4	4	5	0	62
Hypnum pallescens (Hedw.) P.Beauv.		2	0	1	0	0	0	0	3
Leucobryum glaucum (Hedw.) Ångstr.		3	0	0	0	0	0	0	3
Leucodon sciuroides (Hedw.) Schwägr.		1	0	0	0	0	0	0	1
Mnium hornum Hedw.	*Mniuhorn*	0	0	1	1	1	1	0	4
Orthotrichum affine Schrad. ex Brid.	*Orthaffi*	7	0	0	0	3	0	0	10
Orthotrichum speciosum Nees	*Orthspec*	16	0	7	4	4	5	0	36
Oxyrrhynchium hians (Hedw.) Loeske	*Oxyrhian*	1	0	3	1	0	0	0	5
Plagiomnium affine (Blandow ex Funck) T.J.Kop.	*Plagaffi*	35	0	5	1	2	2	0	45
Plagiomnium cuspidatum (Hedw.) T.J.Kop.	*Plagcusp*	4	0	3	1	3	1	0	12
Plagiomnium ellipticum (Brid.) T.J.Kop.	*Plagelli*	1	0	1	1	1	2	0	6
Plagiomnium undulatum (Hedw.) T.J. Kop.	*Plagundu*	4	0	4	1	3	0	0	12
Plagiothecium cavifolium (Brid.) Z.Iwats.*		1	0	1	0	1	0	0	3
Plagiothecium curvifolium Schlieph. ex Limpr.		0	0	1	0	0	0	0	1
Plagiothecium denticulatum (Hedw.) Schimp.		2	0	0	0	0	1	0	3
Plagiothecium laetum Schimp.	*Plaglaet*	20	0	3	1	2	2	0	28
Platygyrium repens (Brid.) Schimp.*	*Platrepe*	3	0	1	1	0	1	0	6
Pleurozium schreberi (Willd. ex Brid.) Mitt.	*Pleuschr*	42	1	7	2	1	4	2	59
Pohlia nutans (Hedw.) Lindb.	*Pohlnuta*	12	0	1	0	0	1	1	15
Polytrichastrum formosum (Hedw.) G.L.Sm.	*Polyform*	3	0	0	1	1	0	0	5
Polytrichastrum longisetum (Sw. ex Brid.) G.L.Sm.		0	0	0	1	0	0	0	1

Species	Abbrev	Forest type							T
		1 (53)	2 (1)	3 (12)	4 (5)	5 (5)	6 (5)	7 (1)	
Polytrichum commune Hedw.	*Polycomm*	3	0	1	0	0	0	0	4
Polytrichum juniperinum Hedw.	*Polyjuni*	12	1	2	0	0	0	1	16
Polytrichum piliferum Hedw.	*Polypili*	5	0	0	0	0	0	0	5
Pseudoleskeella nervosa (Brid.) Nyholm	*Pseunerv*	0	0	2	1	1	0	0	4
Pseudoscleropodium purum (Hedw.) M.Fleisch.		1	0	0	0	0	0	0	1
Ptilium crista-castrensis (Hedw.) De Not.	*Ptilcris*	10	0	0	1	0	0	0	11
Pylaisia polyantha (Hedw.) Schimp.	*Pylapoly*	18	0	6	1	4	4	0	33
Racomitrium canescens (Hedw.) Brid.	*Racocane*	10	0	0	0	0	0	0	10
Rhizomnium punctatum (Hedw.) T.J.Kop.		0	0	0	1	1	0	0	2
Rhodobryum roseum (Hedw.) Limpr.	*Rhodrose*	4	0	0	0	0	2	1	7
Rhytidiadelphus squarrosus (Hedw.) Warnst.	*Rhytsqua*	20	1	1	1	2	2	0	27
Rhytidiadelphus triquetrus (Hedw.) Warnst.	*Rhyttriq*	16	0	2	1	1	1	0	21
Sanionia uncinata (Hedw.) Loeske	*Saniunci*	6	0	3	1	0	1	0	11
Schistidium apocarpum (Hedw.) Bruch & Schimp.		1	0	0	0	0	0	0	1
Sciuro-hypnum oedipodium (Mitt.) Ignatov & Huttunen	*Sciuoedi*	5	0	1	0	0	1	0	7
Sciuro-hypnum reflexum (Starke) Ignatov & Huttunen		0	0	1	0	1	0	0	2
Sphagnum angustifolium (C.E.O.Jensen ex Russow) C.E.O.Jensen *		1	0	0	0	0	0	1	2
Sphagnum capillifolium (Ehrh.) Hedw.*	*Sphacapi*	2	1	0	0	0	0	1	4
Sphagnum girgensohnii Russow*	*Sphagirg*	3	1	1	0	0	0	2	7
Sphagnum magellanicum Brid.*		0	0	0	0	0	0	1	1
Sphagnum palustre L.*		0	1	0	0	0	0	2	3
Sphagnum squarrosum Crome*	*Sphasqua*	2	0	1	0	0	0	1	4
Sphagnum warnstorfii Russow*		0	0	0	0	0	0	1	1
Syntrichia ruralis (Hedw.) F.Weber & D.Mohr	*Syntrura*	6	0	1	0	0	0	0	7
Tetraphis pellucida Hedw.	*Tetrpell*	6	0	1	2	0	1	1	11
Thuidium delicatulum (Hedw.) Schimp.	*Thuideli*	5	0	0	2	0	0	0	7
Thuidium tamariscinum (Hedw.) Schimp.		1	0	0	0	0	0	0	1
Tortula muralis Hedw.*		1	0	0	0	0	0	0	1
Ulota crispa (Hedw.) Brid.*		0	0	0	1	1	1	0	3
Hepatics									

Species	Abbrev	Forest type							T
		1 (53)	2 (1)	3 (12)	4 (5)	5 (5)	6 (5)	7 (1)	
Barbilophozia barbata (Schmidel. ex Schreb.) Loeske		1	0	0	0	0	0	0	1
Cephalozia bicuspidata (L.) Dumort.		1	0	0	0	1	0	0	2
Chiloscyphus pallescens (Ehrh.) Dumort.		1	0	1	0	0	0	0	2
Lepidozia reptans (L.) Dumort.	*Lepirept*	2	0	0	0	1	0	0	3
Lophocolea bidentata (L.) Dumort.*		0	0	1	0	0	0	0	1
Lophocolea heterophylla (Schrad.) Dumort.	*Lopheter*	22	1	8	2	4	4	1	42
Lophozia ventricosa (Dicks.) Dumort.		0	0	0	0	0	0	1	1
Marchantia polymorpha (L.)		0	0	1	0	0	0	0	1
Nowellia curvifolia (Dicks.) Mitt.		3	0	0	0	0	0	0	3
Pellia epiphylla (L.) Corda		1	0	0	0	0	0	0	1
Ptilidium ciliare (L.) Hampe	*Ptilcili*	3	0	1	0	0	0	0	4
Ptilidium pulcherrimum (Weber) Vain.	*Ptilpulc*	16	0	2	2	0	3	0	23
Radula complanata (L.) Dumort.	*Raducomp*	11	0	4	2	3	4	0	24
LICHENS									
Anaptychia ciliaris (L.) Körb.		1	0	0	1	0	0	0	2
Candelariella xanthostigma (Ach.) Lettau		1	0	0	0	1	0	0	2
Cetraria aculeata (Schreb.) Fr.	*Cetracul*	5	0	0	0	0	0	0	5
Cetraria islandica (L.) Ach.	*Cetrisla*	13	0	0	0	0	0	0	13
Chaenotheca ferruginea (Turner & Borrer) Mig.*	*Chaeferr*	23	1	1	3	1	3	0	32
Cladonia arbuscula (Wallr.) Flot.	*Cladarbu*	12	0	0	0	0	0	0	12
Cladonia cenotea (Ach.) Schaer.*		1	0	0	0	0	0	0	1
Cladonia cervicornis (Ach.) Flot.*		1	0	0	0	0	0	0	1
Cladonia chlorophaea (Flörke ex Sommerf.) Spreng.	*Cladchlo*	4	0	1	0	0	1	0	6
Cladonia ciliata Stirt. *		1	0	0	0	0	0	0	1
Cladonia coniocraea (Flörke) Spreng.*	*Cladconi*	21	1	2	3	0	0	2	29
Cladonia crispata (Ach.) Flot.		1	0	0	0	0	0	0	1
Cladonia deformis (L.) Hoffm.*		1	0	0	0	0	0	0	1
Cladonia fimbriata (L.) Fr.	*Cladfimb*	10	0	1	0	1	2	0	14
Cladonia furcata (Huds.) Schrad.	*Cladfurc*	10	0	0	0	0	0	0	10
Cladonia glauca Flörke*		1	0	0	0	0	0	0	1
Cladonia gracilis (L.) Willd.*	*Cladgrac*	6	0	0	0	0	0	0	6
Cladonia mitis Sandst.	*Cladmiti*	4	0	0	0	0	0	0	4
Cladonia portentosa (Dufour) Coem.*		1	0	0	0	0	0	0	1
Cladonia rangiferina (L.) F. H. Wigg.	*Cladrang*	7	0	1	0	0	0	0	8
Cladonia rangiformis Hoffm.*		1	0	0	0	0	0	0	1

Species	**Abbrev**	**Forest type**							**T**
		1 (53)	**2 (1)**	**3 (12)**	**4 (5)**	**5 (5)**	**6 (5)**	**7 (1)**	
Cladonia scabriuscula (Delise) Nyl.		3	0	0	0	0	0	0	3
Cladonia squamosa Hoffm.*		2	0	0	0	0	0	0	2
Cladonia stellaris (Opiz) Pouzar & Vezda*		1	0	0	0	0	0	0	1
Cladonia subulata (L.) Weber ex F.H. Wigg.*	*Cladsubu*	4	0	1	0	0	0	0	5
Cladonia turgida Hoffm.*		1	0	0	0	0	0	0	1
Cladonia uncialis (L.) Weber ex F. H. Wigg.		1	0	0	0	0	0	0	1
Evernia prunastri (L.) Ach.		3	0	0	0	0	0	0	3
Graphis scripta (L.) Ach.*		0	0	0	1	0	0	0	1
Hypocenomyce scalaris (Ach.) M. Choisy	*Hyposcal*	13	0	0	0	0	1	0	14
Hypogymnia physodes (L.) Nyl.	*Hypophys*	21	0	3	3	1	2	0	30
Imshaugia aleurites (Ach.) S. L. F. Meyer*		0	0	0	1	0	0	0	1
Lecanora allophana Nyl.*		5	0	0	0	2	1	0	8
Lecanora subrugosa Nyl.*		1	0	1	0	0	0	0	2
Lecidella euphoria (Flörke) Hertel.*		1	0	0	0	1	0	0	2
Lepraria incana (L.) Ach.*	*Leprinca*	34	1	8	3	4	5	1	56
Lepraria lobificans Nyl.*	*Leprsp.*	0	0	1	0	0	0	0	1
Lepraria jackii Tønsberg*		1	0	0	0	0	0	0	1
Melanohalea exasperatula (Nyl.) O. Blanco A. Crespo, Divakar, Essl, D. Hawksw. & Lumbsch	*Melanoha*	0	0	2	1	1	1	0	5
Parmelia sulcata Taylor	*Parmsulc*	6	0	3	2	2	4	0	17
Parmeliopsis ambigua (Wulfen) Nyl.	*Parmambi*	4	0	0	0	0	0	0	4
Peltigera canina (L.) Willd.	*Peltcani*	6	0	1	1	0	0	0	8
Peltigera didactyla (With.) J.R. Laundon*	*Peltdida*	4	0	1	0	0	0	0	5
Peltigera hymenina (Ach.) Delise*		1	0	0	0	0	0	0	1
Peltigera malacea (Ach.) Funck		2	0	0	0	0	0	0	2
Peltigera membranacea (Ach.) Nyl.*		1	0	0	0	0	0	0	1
Peltigera neckeri Hepp ex Müll. Arg.*		1	0	0	0	0	0	0	1
Peltigera praetextata (Flörke ex Sommerf.) Zopf*		0	0	1	0	0	0	0	1
Peltigera rufescens (Weiss) Humb.		3	0	0	0	0	0	0	3
Phaeophyscia orbicularis (Neck.) Moberg		0	0	1	0	1	0	0	2
Phlyctis argena (Spreng.) Flot.*	*Phlyarge*	9	0	4	2	1	2	0	18
Physcia adscendens (Fr.) H. Olivier		1	0	0	0	0	0	0	1
Physcia stellaris (L.) Nyl.		1	0	0	0	0	0	0	1
Physcia tenella (Scop.) DC.		2	0	1	0	1	0	0	4

Species	Abbrev	Forest type							T
		1 (53)	**2 (1)**	**3 (12)**	**4 (5)**	**5 (5)**	**6 (5)**	**7 (1)**	
Physconia distorta (With.) J. R. Laundon		1	0	0	0	0	0	0	1
Platismatia glauca (L.) W. L. Culb. & C. F. Culb.		2	0	0	0	0	0	0	2
Pseudevernia furfuracea (L.) Zopf		3	0	0	0	0	0	0	3
Ramalina farinacea (L.) Ach.		0	0	0	0	1	0	0	1
Xanthoria parietina (L.) Th. Fr.	*Xantpari*	5	0	3	0	1	0	0	9
Xanthoria polycarpa (Hoffm.) Th. Fr. ex Rieber		0	0	0	1	0	0	0	1