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# Diversity and distribution of epiphytic lichens and bryophytes on aspen *(Populus tremula)* in the middle boreal forests of Republic of Karelia (Russia)

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**Abstract:** The distribution of epiphytic bryophyte and lichen species growing on aspen in the middle boreal forests was studied in southern Karelia (Russia). These forests varied in time-since-disturbance from 80 to 450 years. Two hundred twenty two species of epiphytes, including 178 lichens, 32 mosses and 12 liverworts, were recorded on 192 aspen trees in forests over 24 ha, in the Karelian part of the Vodlozero National Park, Kivach Strict Nature Reserve, Kizhi Sanctuary and Petrozavodsk City. *Arthonia biatoricola*, *A. excipienda* and *Biatoridium monasteriense* were collected in Karelia for the first time. Eighteen rare species (lichens *Anaptychia ciliaris*, *Arthonia vinosa*, *Bryoria nadvornikiana*, *Chaenotheca gracilenta*, *C. stemonea*, *Lecidea albofuscescens*, *Lobaria pulmonaria*, *Melanelixia subaurifera*, *Nephroma bellum*, *N. laevigatum*, *Phaeocalicium populneum*, *Ramalina thrausta*, *Rostania occultata*, *Scytinium subtile*, *Usnea barbata*, mosses *Neckera pennata*, *Plagiomnium drummondii* and liverwort *Lejeunea cavifolia*) listed in the Red Data Book of Republic of Karelia (2007) were found. Relationships between epiphytic lichen and bryophyte species richness and certain environmental variables (at different trunk heights above ground and time-since-disturbance) were evaluated. Lichens and mosses on aspen trunks often occupy different ecological niches. Cover and diversity of bryophytes was high on trunk bases, while the number of lichen species and their cover were higher at a height of 1.3 m above ground level. The total number of lichen species on aspen increased on average from 40 to 60 species per ha with increasing time-since-disturbance from 100 to 450 years. A stabilization in lichen species number was observed at about 200 years since disturbance. No significant correlation was determined between bryophyte diversity on aspens and the time-since-disturbance.

**Keywords:** epiphytes on aspen; middle boreal forests; lichens; bryophytes; liverworts; time-since-disturbance

## INTRODUCTION

Epiphytic lichens and bryophytes are important components of many forest ecosystems. They exhibit high species diversity, form conspicuous biomass and play a significant ecological role in boreal ecosystems (Esseen et al., 1996; Glime, 2007). In addition, lichen epiphytes are useful indicators of forest health because they are sensitive to forest management practices and serve as indicators of air quality (Lesica et al., 1991; Richardson, 1992; McCune, 2000). According to literature, the most important factors influencing epiphytic bryophyte and lichen distribution are forest stand age (Fritz et al., 2008; Mežaka et al., 2010), host tree (Lõhmus et al., 2007; Mežaka et al., 2008; Strazdina, 2010), tree age (Barkman, 1958; Hedenås & Eriksson, 2000; Ojala et al., 2000) and microclimate (John & Dale, 1995).

Aspen (*Populus tremula* L.) is a common deciduous tree species in the middle and south boreal taiga, which can form secondary forests (pure aspen stands and mixed aspen-spruce stands). Aspen also occurs in mesic stands in old-growth spruce forests by renewal in canopy gaps due to natural gap dynamics (Kuusinen, 1994; Hazell et al., 1998). It reproduces mainly vegetatively by root suckers. Mature aspen trees (their trunks and roots) are frequently attacked by several pathogenic fungi, for example by *Phellinus tremulae* (Bondartsev) Bondartsev & P. N. Borisov (Kuusinen, 1994). In spite of this, *Populus* trees often reach an age of 200 years in Scandinavian forests (Kuusinen, 1994). Aspen trees in suitable habitats usually grow very quickly, and may reach large proportions – tree height up to 40 m, diameter at breast height (DBN) up to 1 m – even when relatively young (Abaimov, 2009). Angles between branches and trunk of aspen are sharp (acute), therefore most rain water intercepted by the crown flows down the tree trunks. High values of tree height, crown length and radius increase stemflow, which in aspen can reach 9% of the total precipitation in the community (Molchanov, 1961). In addition, the aspen tree usually does not shed its bark. Aspen has a rather nutrient-rich bark with a relatively high pH (5–7) and moisture capacity (Barkman, 1958; Gustafsson & Eriksson, 1995). Therefore, aspen provides an important substrate for many epiphytes (Kuusinen, 1994; Gustafsson & Eriksson, 1995), including lichens, bryophytes and liverworts.

Epiphyte diversity on *Populus tremula* in boreal forests in Europe has been intensively studied (Shubina et al., 1996; Uliczka & Angelstam, 1999; Lõhmus, 2003). Many researches focused on studying aspen as an important component in preserving biodiversity in boreal forests, because large numbers of specialist species are entirely dependent on this species (Kuusinen & Siitonen, 1998; Pykälä et al., 2006). There were the studies on cyanolichens and lichens associated with *Lobaria pulmonaria* (L.) Hoffm. on aspen, which is the one of main host trees for these lichens in boreal forests in Europe (Gauslaa, 1995; Kuusinen, 1996; Gjerde et al., 2012). However, the epiphytic lichen and bryophyte diversity of aspen in northwest Russia is still poorly studied (Pystina & Hermansson, 1996; Mikhailova et al., 2005). The main aim of the current research was to inventory the lichen and bryophyte diversity associated with aspen trees in the middle boreal forests of Republic of Karelia.

## MATERIALS AND METHODS

### Study areas

Study was carried out during summer 2014 and 2015 in mesic, middle boreal forests in the southern part of the Republic of Karelia, Russia. The climate is predominantly temperate and intermediate ranging from oceanic to continental and characterized by having relatively mild, long winters and cool, short summers. The mean annual temperature is +3°C and the mean annual precipitation is 450–750 mm (Nazarova, 2003). The area is flat, varying not more than 100 m in elevation. Low humic podzolic soils predominate in not waterlogged habitats (Morozova, 1991). Forests cover more than 54% of the Karelian territory. Pine communities predominate (64% of the forested area), while spruce communities occupy 25% of the area (Volkov, 2008). Over the past 80 years, the area of small-leaved secondary forests in Karelia has tripled due to intensive forest management and now they occupy 11% of the forested territory. Aspen stands occupy 4.2% of the forested territory in the middle taiga (Volkov, 2008).

Research was carried out in four study areas: the Karelian part of the Vodlozero National Park, Kivach Strict Nature Reserve, Kizhi Sanctuary and Petrozavodsk City (Fig. 1). In each territory, permanent sample plots of one ha (100 × 100 m) were established in communities at different successional stages, belonging to the same ecological-dynamic series. These communities represent the process of restoration of climax spruce forest of *Vaccinium myrtillus* – green mosses type, occupying plains on loamy moraine, without stagnant moisture. In general, spruce forests after fire or clear cuttings regenerate through different early serial stages, usually involving birch or aspen (Kazimirov, 1971; Dyrenkov, 1984), with aspen on richer soils and birch on poorer ones (Ipatov, 1960; Degteva et al., 2001). In this study, the successional dynamics of spruce forests at different successional stages varying in time-since-disturbance from 80 to 450 years is considered (Table 1). Based on literature data of successions in the mid-taiga spruce forests (Kazimirov, 1971; Dyrenkov, 1984), all studied communities correspond to four groups according to different stages of the ecological-dynamic series:

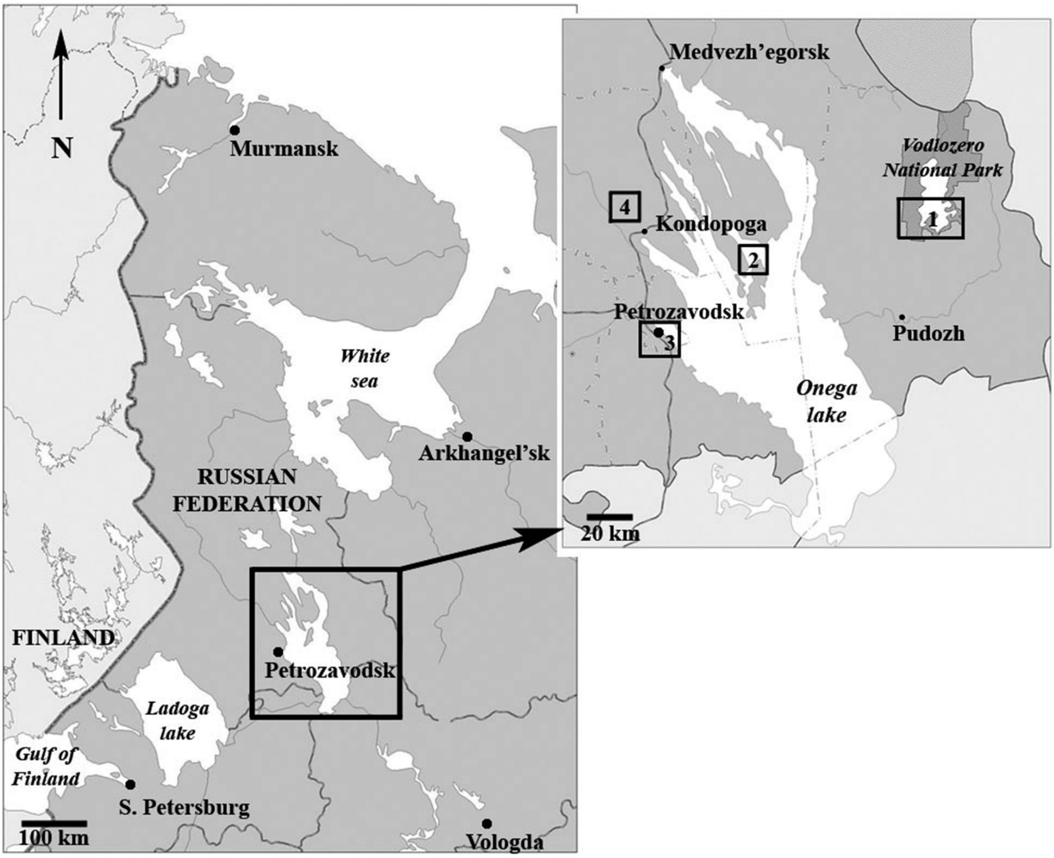


**Fig. 1.** The location of the study areas (Republic of Karelia, NW Russia): 1 – Vodlozero National Park, 2 – Kizhi Sanctuary, 3 – Kivach Strict Nature Reserve, 4 – Petrozavodsk City.

1) middle-aged aspen forest *Calamagrostis arundinacea–Vaccinium myrtillus* type; 2) mixed aspen-spruce forest *Vaccinium myrtillus–Calamagrostis arundinacea* type; 3) pre-climax spruce forest *Vaccinium myrtillus*–green mosses type; 4) climax (old-growth) spruce forest *Vaccinium myrtillus*–green mosses type (Table 1). In each study area, forests communities from the first three stages of succession were represented, while all successional stages of spruce forest were studied in the Vodlozero National Park only. The main characteristics of the studied forest communities on 24 sample plots are given in Table 1.

**Data collection**

To estimate time-since-disturbance in the studied communities, the population structure of each tree stand (mainly spruce trees) was evaluated following Stavrova et al. (2016). This method is described in detail in Ignatenko & Tarasova (2017). Eight aspen trees were randomly chosen within each sample plot to assess epiphytic biodiversity (lichens, lichenicolous and non-lichenized fungi, mosses and liverworts). Species diversity and cover of lichens, mosses and liverworts were estimated by means of a 25 × 25 cm frame at the northern, southern, eastern and western sides of a trunk at the base and breast height (at 1.3 m from base). In addition, species diversity was recorded on branches of recently fallen aspen trees within each sample plot. In total, 1535 descriptions of the epiphytic cover were made on 192 aspen trees from 24 sample plots (Vodlozero National Park – 7 sample plots, Kizhi Sanctuary – 6, Kivach Strict Nature Reserve – 8, Petrozavodsk City – 3).

**Table 1.** Main characteristics of studied forest communities in the middle taiga of Republic of Karelia. Study areas,1 – Vodlozero National Park, 2 – Kizhi Sanctuary, 3 – Kivach Strict Nature Reserve, 4 – Petrozavodsk City; type of forests, a – middle-aged aspen forest *Vaccinium myrtillus*–*Calamagrostis arundinacea* type, a-s – mixed aspen-spruce forest *Calamagrostis arundinacea*–*Vaccinium myrtillus* type, spc – pre-climax spruce forest *Vaccinium myrtillus*–green mosses type, sc – climax (old-growth) spruce forest *Vaccinium myrtillus*–green mosses type.

| Study area | No of sample plot | GPS coordinate | Type of forest | Time-since-disturbance, years | Basal area, $m^2ha^{-1}$ | Proportion in the tree stand, % | | Tree age, years | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Spruce | Aspen | Spruce | Aspen |
| 1 | 1 | 62°13.448'N, 36°45.222'E | spc | 260 | 19.3 | 64 | 2 | 46–229 | 128–152 |
| | 2 | 62°12.001'N, 36°51.114'E | a | 80 | 29 | 8 | 33 | 28–48 | 26–73 |
| | 3 | 62°12.076'N, 36°50.249'E | a-s | 180 | 31 | 65 | 14 | 48–143 | 67–151 |
| | 4 | 62°11.972'N, 36°51.009'E | a-s | 160 | 26.5 | 53 | 22 | 28–84 | 83–151 |
| | 5 | 62°11.976'N, 36°49.659'E | a | 100 | 30.3 | 27 | 45 | 25–95 | 56–103 |
| | 6 | 62°13.545'N, 37°05.081'E | sc | 410 | 22.8 | 81 | 12 | 24–263 | 164–198 |
| | 7 | 62°13.026'N, 37°03.456'E | sc | 450 | 29.3 | 89 | 9 | 31–180 | 109–203 |
| 2 | 1 | 62°06.727'N, 35°09.241'E | a-s | 160 | 30.5 | 42 | 35 | 61–122 | 84–132 |
| | 2 | 62°06.619'N, 35°09.353'E | a-s | 150 | 31 | 51 | 29 | 42–126 | 71–130 |
| | 3 | 62°07.057'N, 36°07.267'E | spc | 260 | 22 | 81 | 13 | 49–192 | 81–169 |
| | 4 | 62°06.897'N, 35°07.252'E | spc | 240 | 28 | 73 | 12 | 22–145 | 88–198 |
| | 5 | 62°06.843'N, 35°09.747'E | a | 85 | 24 | 1 | 60 | 36–55 | 39–85 |
| | 6 | 62°06.902'N, 35°09.546'E | a | 100 | 19 | 5 | 68 | 36–75 | 39–97 |
| 3 | 1 | 61°44.906'N, 34°21.906'E | a | 110 | 25 | 34 | 38 | 19–78 | 57–104 |
| | 2 | 61°44.268'N, 34°19.202'E | a-s | 160 | 32 | 44 | 43 | 38–150 | 53–117 |
| | 3 | 61°50.472'N,34°30.482'E | spc | 210 | 28 | 59 | 22 | 84–168 | 87–119 |
| 4 | 1 | 62°16.678'N, 33°59.135'E | a-s | 170 | 27 | 61 | 22 | 30–147 | 73–163 |
| | 2 | 62°16.599'N, 33°59.706'E | a-s | 160 | 31 | 38 | 38 | 46–126 | 72–115 |
| | 3 | 62°16.517'N, 33°59.828'E | a-s | 170 | 37 | 45 | 44 | 28–82 | 63–169 |
| | 4 | 62°15.794'N, 33°58.855'E | a | 80 | 39 | 30 | 68 | 31–72 | 42–80 |
| | 5 | 62°15.879'N, 33°58.730'E | a-s | 190 | 23.5 | 46 | 35 | 21–153 | 47–161 |
| | 6 | 62°15.997'N, 33°59.685'E | a-s | 170 | 33.5 | 53 | 32 | 21–132 | 102–169 |
| | 7 | 62°17.051'N, 33°58.271'E | spc | 240 | 21 | 74 | 13 | 24–159 | 97–186 |
| | 8 | 62°17.225'N, 33°57.817'E | spc | 250 | 26 | 77 | 12 | 21–211 | 92–156 |

Collected material was identified in the Herbarium of the Botanical Museum, Finnish Museum of Natural History, University of Helsinki; Department of Botany and Plant Physiology, Petrozavodsk State University; Department of Botany, St. Petersburg State University; Laboratory of Mire Ecosystems, Institute of Biology of Karelian Research Centre RAS, Petrozavodsk; Laboratory of Terrestrial Ecosystems, Institute of the Industrial Ecology Problems of the North of the Kola Science Centre RAS, Apatity and Laboratory for Boreal Forest Dynamics and Production, Forestry Research Institute of Karelian Research Centre RAS, Petrozavodsk. Selected specimens from genus *Cladonia* and sterile crustose lichens were identified by a standard technique of thin-layer chromatography (TLC) in the Laboratory of Experimental Botany of Petrozavodsk State University, Petrozavodsk, using solvent systems A, B and C (Orange et al., 2001). In total, 400 specimens of mosses and liverworts and 3447 specimens of lichensand allied fungi were identified; 188 specimens were identified using TLC. Representative specimens were deposited in the herbarium of Petrozavodsk State University (PZV); doublet liverwort specimens were kept in the herbarium of the Institute of the Industrial Ecology Problems of the North of the Kola Science Centre RAS (INEP). Simple non-linear regression analysis was used to evaluate the relationships between species number (separately for lichens, mosses and liverworts) and the time-since-disturbance. Comparison between groups of the main characteristics of lichen and bryophyte distribution (cover and number of species) were tested by means of Mann–Whitney one-way analysis of variance. The program Statgraphics Centurion XV (2006) was used.

### List of localities

The following study areas were investigated: KvR – Kivach Strict Nature Reserve (10,450 ha), Kondopoga District, 62˚20'N, 34˚00'E, biogeographical province *Karelia onegensis* (*Kon*); Ptz – Petrozavodsk City (11300 ha), Prionezhsky District, 61˚50'N, 34˚20'E, biogeographical provinces *Karelia onegensis* and *Karelia olonetsensis* (*Kol*); VNP – Karelian part of the Vodlozero National Park (130,600 ha), Pudozh district, 62˚30'N, 36˚55'E, biogeographical province *Karelia transonegensis* (*Kton*); KzR – Kizhi Sanctuary (50,000 ha), Medvezh'egorsk District, Zaonezhsky Peninsula, 62˚12'N, 35˚14'E, biogeographical province *Karelia onegensis*.

## THE SPECIES

Taxa are arranged in alphabetical order; nomenclature of lichens, lichenicolous and non-lichenized fungi follows mainly Nordin et al. (2011), nomenclature of liverworts mainly Söderström et al. (2016) with some updates from other literature (Konstantinova et al., 2009), and nomenclature of mosses – Hill et al. (2006).

Abbreviations and symbols: # – lichenicolous fungi; + – non-lichenized fungi; ! – new species for Republic of Karelia; *Kol!* – new species for the biogeographical province *Karelia olonetsensis*, *Kon!*– new species for the biogeographical province *Karelia onegensis*, *Kton!* – new species for the biogeographical province *Karelia transonegensis*; KvR!, KzR!, Ptz!, VNP! – new species for study areas: KvR – Kivach Strict Nature Reserve, KzR – Kizhi Sanctuary, Ptz – Petrozavodsk City, VNP – Vodlozero National Park; other biogeographical provinces: *Kl* –*Karelia ladogensis*, *Kk* – *Karelia keretina*, *Ks* – *Regio kuusamoënsis*. Species included in the Red Data Book of the Republic of Karelia (2007) are marked as RK, and in the Red Data Book of the Russian Federation (2008) – RR. The types of forest communities are marked with the numbers 1–4 (see Tab. 1). KzR!? – exact locality of this species, published by Norrlin (1876) for Zaonezhsky Peninsula (included the area of Kizhi Sanctuary) (Fadeeva et al., 2014), is not established due to old toponyms.

### a. Lichens, lichenicolous and non-lichenized fungi

Acrocordia gemmata (Ach.) A. Massal. – KzR: 2. *Kon*! KzR!

Alyxoria varia (Pers.) Ertz & Tehler – KvR, KzR, VNP: 1–4. *Kton*! KzR!

Amandinea punctata (Hoffm.) Coppins & Scheid. – VNP: 2.

Anaptychia ciliaris (L.) Körb. – Ptz: 2. RK.

Anisomeridium polypori (Ellis & Everh.) M. E. Barr – KvR, KzR, Ptz, VNP: 1–4. *Kon*! *Kol*! *Kton*! KvR! KzR! Ptz! VNP!

Arctomia fascicularis (L.) Otálora & Wedin – KvR: 2; VNP: 4. This species was recently found in Karelia in provinces *Kon* and *Kton* (Tarasova & Stepanchikova, 2016).

Arthonia apatetica (A. Massal.) Th. Fr. – KvR, Ptz: 1–3. *Kon*! KvR!

!#Arthonia biatoricola Ihlen & Owe-Larss. – KvR: right bank of the Suna River, below Kivach waterfall, 62˚15.879'N, 33˚58.730'E, on thalli of *Biatora efflorescens*, 2,19.09.2015. *Kon*! KvR! This recently described lichenicolous fungus belongs to the *Arthonia radiata* group (Ihlen et al., 2004). The species was only known from Norway, Sweden and the USA (Alaska) (Ihlen et al., 2004), in Russia – from Leningrad region (Stepanchikova et al., 2013).

Arthonia didyma Körb. – KvR, KzR, Ptz, VNP: 1–4. *Kol*! *Kton*! KzR! VNP!

!Arthonia excipienda (Nyl.) Nyl. – KvR: right bank of the Suna River, below Kivach waterfall, 62˚15.794'N, 33˚58.855'E, 1, 20.09.2015; same locality, 62˚15.879'N, 33˚58.730'E, 2, 19.09.2015; left bank of the Suna River, 62˚15.997'N, 33˚59.685'E, 2, 16.09.2014. VNP: bank of Vodlozero Lake near from the mouth of the Vama River, 62˚13.026'N, 37˚03.456'E, 4. 14.06.2015. *Kon*! *Kton*! KvR! VNP! This crustose lichen inhabits smooth bark of *Alnus*, *Corylus*, *Berberis* and *Daphne* spp. (Nordin et al., 2011). In Russia, the species was previously known from Murmansk region (Urbanavichus et al., 2008), Leningrad region (Kuznetsova et al., 2007) and Kaliningrad region (Dedkov et al., 2007). Distribution in Fennoscandia: Norway, Sweden, Finland (Nordin et al., 2011).

Arthonia mediella Nyl. – KvR, KzR, Ptz, VNP: 2–4. *Kton*! KzR!? VNP!

Arthonia patellulata Nyl. – KvR, KzR, Ptz, VNP: 1–3. *Kton*! KzR! VNP!

Arthonia radiata (Pers.) Ach. – KvR, KzR, VNP: 1–3. KzR!?

Arthonia vinosa Leight. – KvR: 2, 3; KzR: 1, 3. KzR! RK.

Athallia pyracea (Ach.) Arup et al. – KvR, KzR, Ptz, VNP: 1–4. KzR!

Bacidia arceutina (Ach.) Rehm & Arnold – KvR, KzR, Ptz: 1–3. *Kol*! KzR!

Bacidia circumspecta (Nyl. ex Vain.) Malme – VNP: 3. *Kton*! VNP!

Bacidia igniarii (Nyl.) Oxner – KvR, KzR, VNP: 1, 2. *Kton*! KvR! KzR! VNP!

Bacidia laurocerasi (Del. ex Duby) Vain. – KvR, KzR, Ptz, VNP: 1–4. This species was recently reported for Karelia in provinces *Kon* and *Kton* (Tarasova & Stepanchikova, 2016; Tarasova et al., 2016a).

Bacidia subincompta (Nyl.) Arnold – KvR, KzR, Ptz, VNP: 1–4. KzR! VNP!

Biatora albohyalina (Nyl.) Bagl. & Carestia – KvR, KzR, Ptz, VNP: 1–4. *Kton*! KzR! VNP!

Biatora efflorescens (Hedl.) Räsänen – KvR, KzR, Ptz, VNP: 1–4. KzR! VNP!

Biatora globulosa (Flörke) Fr. – ZvR: 2, VNP: 3. *Kton*! VNP!

Biatora helvola Korb ex Hellb. – KvR, KzR, Ptz, VNP: 1–4. *Kol*! KzR!

Biatora ocelliformis (Nyl.) Arnold – KvR, KzR, Ptz, VNP: 1–4. *Kol*! *Kton*! KzR! VNP!

Biatora vernalis (L.) Fr. – Ptz: 1; KzR: 3.

!Biatoridium monasteriense J. Lahm ex Körb. – KvR: right bank of the Suna River, below Kivach waterfall, ca. 50 m from the river, 62°15.794'N, 33°58.855'E, 1, 20.09.2015; right bank of the Suna River, over Kivach waterfall, central cutting line, ca. 350 m from river, 62°17.051'N, 33°58.271'E, 3, 26.09.2015. *Kon*! KvR! The crustose lichen inhabits bark of deciduous trees *Ulmus*, *Fraxinus*, *Populus* spp. (Nordin et al., 2011). This species was known from different regions of central European Russia and in the southern part of North-West Russia (Urbanavichus, 2010). This locality is currently the northernmost in Russia. The nearest and previously northernmost known locality was from Leningrad region (Alexeeva & Himelbrant, 2007; Stepanchikova et al., 2011). The distribution in Fennoscandia: Norway, Sweden and Finland (Nordin et al., 2011).

Bilimbia microcarpa (Th. Fr.) Th. Fr. – KvR, VNP: 1–4. *Kton*! VNP!

Bilimbia sabuletorum (Schreb.) Arnold – KvR, KzR, Ptz, VNP: 1–3. *Kton*! KvR! KzR! VNP!

Bryobilimbia hypnorum (Lib.) Fryday, Printzen & S. Ekman – VNP: 2. *Kton*! VNP!

Bryoria capillaris (Ach.) Brodo & D. Hawksw. – KvR, KzR, Ptz, VNP: 2–4.

Bryoria implexa (Hoffm.) Brodo & D. Hawksw. – KvR: 2; VNP: 4.

Bryoria nadvornikiana (Gyeln.) Brodo & D. Hawksw. – KzR: 3. RK.

Bryoria vrangiana (Gyeln.) Brodo & D. Hawksw. – Ptz: road to Barany Bereg village, ca. 2 km of Onega Lake, 61°50.472'N, 34°30.482'E, 3, 22.05.2016. Det. L. Myllys. This species could be rather common in Karelia. The revision of specimens, published as *B. fuscescens* and *B. implexa*, is required due to the new data on taxonomy of *B. implexa* group (Velmala et al., 2014). The species was known in Karelia from historical (XIX century) and present collections from Petrozavodsk only (*Kon*, *Kol*) (Tarasova et al., 2013, 2015).

Buellia erubescens Arnold – KvR: 2; KzR: 1. *Kon*! KvR! KzR!

Buellia disciformis (Fr.) Mudd – KvR: 2; VNP: 1, 4.

Caloplaca borealis (Vain.) Poelt – VNP: 3. *Kton*! VNP!

Caloplaca cerina (Ehrh. ex Hedw.) Th. Fr. – KvR, KzR, Ptz, VNP: 1–4.

Candelariella superdistans (Nyl.) Malme – VNP: 2. *Kton*! VNP!

Candelariella vitellina (Ehrh.) Müll. Arg. – VNP: 1, 2. *Kton*! VNP!

Catinaria neuschildii (Körb.) P. James – KvR: 2, 3; KzR: 2; Ptz: 3. This species recently reported in Karelia in provinces *Kon* and *Kton* (Tarasova & Stepanchikova, 2016; Tarasova et al., 2016a).

Catinaria atropurpurea (Schaer.) Vězda & Poelt – KvR, Ptz, VNP: 1–4. *Kton*! KvR! VNP!

Chaenotheca brachypoda (Ach.) Tibell – KvR, KzR, Ptz, VNP: 1–3.

CHAENOTHECA CHLORELLA (Ach.) Müll. Arg. – KvR, KzR: 3. KzR!

CHAENOTHECA CHRYSOCEPHALA (Turner ex Ach.) Th. Fr. – KzR: 1.

CHAENOTHECA FURFURACEA (L.) Tibell – KvR: 3.

CHAENOTHECA GRACILENTA (Ach.) Mattsson & Middelb. – KvR: 2; VNP: 4. VNP! RK.

CHAENOTHECA HISPIDULA (Ach.) Zahlbr. – Ptz: road to Barany Bereg villiage, ca. 2 km of Onega Lake, 3. It was the second finding in Karelia (Tarasova et al., 2016a). The species was previously known from the Kivach Strict Nature Reserve (*Kon*) (Hermansson et al., 2002).

CHAENOTHECA LAEVIGATA Nádv. – KvR: 2, 3; VNP: 3. Kton! VNP!

CHAENOTHECA STEMONEA (Ach.) Müll. Arg. – KvR: 2. RK.

#CHAENOTHECOPSIS CONSOCIATA (Nádv.) A. F. W. Schmidt – KzR: 1, on thalli of *Chaenotheca chrysocephala*. KzR!

+CHAENOTHECOPSIS DEBILIS (Sm.) Tibell – KvR: 1. *Kon*! KvR! The species was only known in Karelia, from *Kl* province (Fadeeva et al., 2007).

#CHAENOTHECOPSIS VAINIOANA (Nádv.) Tibell – KvR, KzR: 3, on thalli of *Arthonia vinosa*. KzR! The species was only known in Karelia from *Kon* province (Fadeeva et al., 2007).

CLADONIA BACILLIFORMIS (Nyl.) Glück – KvR, KzR, VNP: 2, 3.

CLADONIA BOTRYTES (K. G. Hagen) Willd. – KvR: 3.

CLADONIA CENOTEA (Ach.) Schaer. – KvR, KzR, VNP: 2–4.

CLADONIA CHLOROPHAEA (Flörke ex Sommerf.) Spreng. – KvR, KzR, Ptz, VNP: 1–4. The specimens contain fumarprotocetraric acid.

CLADONIA CONIOCRAEA (Flörke) Spreng. – KvR, KzR, Ptz, VNP: 1–4.

CLADONIA CORNUTA (L.) Hoffm. – KvR, KzR, Ptz, VNP: 1–3.

CLADONIA CYANIPES (Sommerf.) Nyl. – Ptz: 2.

CLADONIA DEFORMIS (L.) Hoffm.– KvR, KzR, VNP: 2, 3.

CLADONIA DIGITATA (L.) Hoffm. – KzR, Ptz: 2, 3.

CLADONIA GRACILIS subsp. TURBINATA (Ach.) Ahti – VNP: 4.

CLADONIA FIMBRIATA (L.) Fr. – KvR, KzR, Ptz, VNP: 1–4.

CLADONIA OCHROCHLORA Flörke – KvR: 1–3; Ptz: 3; VNP: 4. *Kton*! KvR! VNP!

CLADONIA PARASITICA (Hoffm.) Hoffm. – KvR: 3.

CLADONIA PHYLLOPHORA Ehrh. ex Hoffm. – KvR: 3.

CLADONIA PLEUROTA (Flörke) Schaer. – KvR: 2; KzR: 3.

CLADONIA PYXIDATA (L.) Hoffm. – KzR: 2, 3.

COENOGONIUM PINETI (Ach.) Lücking & Lumbsch – KvR: 2, 3.

COLLEMA FURFURACEUM Du Rietz – KvR, KzR, VNP: 1–3. KzR!

EOPYRENULA LEUCOPLACA (Wallr.) R. C. Harris – KvR: 2. KvR! The species was known in Karelia from historical collection made in *Kl* and *Kon* provinces (Fadeeva et al., 2007).

EVERNIA MESOMORPHA Nyl. – KzR: 1.

EVERNIA PRUNASTRI (L.) Ach. – KzR: 1; Ptz: 3; VNP: 1.

FUSCIDEA PUSILLA Tønsberg – VNP: 1. *Kton*! VNP! The specimen contains divaricatic acid.

GYALECTA TRUNCIGENA (Ach.) Hepp – KvR, KzR, Ptz, VNP: 1–4. *Kton*! KzR! VNP!

GYALOLECHIA FLAVORUBESCENS (Hudson) Søchting et al. – KvR, KzR, Ptz, VNP: 1–3. *Kol*! *Kton*! VNP!

HYPOGYMNIA PHYSODES (L.) Nyl. – KvR, KzR, Ptz, VNP: 1–4.

HYPOGYMNIA TUBULOSA (Schaer.) Hav. – VNP: 2, 3.

LECANIA CYRTELLA (Ach.) Th. Fr. – KvR: 2. KvR!

LECANIA CYRTELLINA (Nyl.) Sandst. – KvR, KzR, Ptz, VNP: 1, 2. *Kton*! KvR! KzR! VNP!

LECANIA DUBITANS (Nyl.) A. L. Sm. – KvR: 2; KzR: 1. KvR! KzR!

LECANIA NAEGELII (Hepp) Diederich & van den Boom – KvR, KzR, Ptz, VNP: 1–3. *Kton*! KvR! KzR! VNP!

LECANORA ALLOPHANA (Ach.) Nyl. – KvR, KzR, Ptz, VNP: 1–3.

LECANORA CARPINEA (L.) Vain. – KvR: 2; VNP: 1, 3, 4. *Kon*! KvR! VNP!

LECANORA CATEILEA (Ach.) A. Massal. – VNP: 4.

LECANORA CHLAROTERA Nyl. – KvR, KzR, Ptz, VNP: 1–4. *Kton*! KzR! VNP!

LECANORA HAGENII (Ach.) Ach. – KvR, KzR, Ptz, VNP: 1–4. *Kton*! KvR! VNP!

LECANORA POPULICOLA (DC.) Duby – KvR, KzR, VNP: 2–4. KzR!

LECANORA SAMBUCI (Pers.) Nyl. – KvR: 2. *Kon*! KvR!

LECANORA SYMMICTA (Ach.) Ach. – Ptz: 3; VNP: 1, 4.

LECIDEA ALBOFUSCESCENS Nyl. – KvR, KzR: 3. *Kon*! KvR! KzR! RK.

LECIDEA BERENGERIANA (A. Massal.) Nyl. – KzR: 3. KzR!

LECIDEA ERYTHROPHAEA Flörke ex Sommerf. – KvR, KzR, Ptz, VNP: 1–4. VNP!

LECIDEA NYLANDERI (Anzi) Th. Fr. – KzR: 2; Ptz:3. KzR!

LECIDELLA ELAEOCHROMA (Ach.) M. Choisy – KvR, KzR, Ptz, VNP: 1–4. *Kton*! KzR! VNP!

Lepraria eburnea J. R. Laundon – KvR, KzR: 3; Ptz: 1.*Kon*! KvR! KzR! The specimens contain alectorialic, protocetraric and psoromic acids.

Lepraria elobata Tønsberg – KvR: 2. *Kon*! KvR! The specimen contains atranorin, zeorin and stictic acid complex. The species was only known in Karelia from *Kk* province (Fadeeva et al., 2007).

Lepraria jackii Tønsberg – KvR, KzR, Ptz, VNP: 1–4. *Kton*! *Kol*! KzR! VNP! The specimens contain atranorin, roccellic/angardianic, jackinic/rangiformic and norjackinic/norrangiformic acids.The species was only known in Karelia from *Kk* (Fadeeva et al., 2007) and *Kon* (Tarasova et al., 2016a, b) provinces.

Lepraria lobificans Nyl. – KvR: 2. KvR! The specimen contains atranorin, zeorin and stictic acid complex.

Leptogium saturninum (Dicks.) Nyl. – KvR, KzR, Ptz, VNP: 1–4.

Leptorhaphis atomaria (Ach.) Szatala – KvR, KzR, VNP: 2. *Kton*! *Kon*! KvR! KzR! VNP!

Lobaria pulmonaria (L.) Hoffm. – KvR, KzR, Ptz, VNP: 1–4. RK, RR.

Lopadium disciforme (Flot.) Kullh. – VNP: 4.

Loxospora elatina (Ach.) A. Massal. – KvR: 2; VNP: 1.

Melanelixia subaurifera (Nyl.) O. Blanco et al. – KzR, Ptz: 1. RK.

Melanohalea exasperata (De Not.) O. Blanco et al. – KvR, KzR, Ptz, VNP: 1–4. KvR! VNP!

Melanohalea olivacea (L.) O. Blanco et al. – KzR, VNP: 1.

Melanohalea septentrionalis (Lynge) O. Blanco et al. – Ptz: 3.

Micarea denigrata (Fr.) Hedl. – KvR, KzR, Ptz, VNP: 1–4. *Kton*! VNP!

Micarea misella (Nyl.) Hedl. – KvR, KzR, VNP: 2–4. *Kton*! KzR! VNP!

Micarea prasina Fr. – KvR, KzR: 2, 3. KzR!

Mycobilimbia carneoalbida (Müll. Arg.) S. Ekman & Printzen – KvR, KzR, Ptz, VNP: 1–4.

Mycobilimbia epixanthoides (Nyl.) Vitik. et al. – KvR, KzR, Ptz, VNP: 1–4.

Mycobilimbia tetramera (De Not.) Vitik. et al. – KvR, KzR, Ptz, VNP: 1–4.VNP!

+Mycocalicium subtile (Pers.) Szatala – KvR: 2; VNP: 3. *Kton*! VNP!

Naetrocymbe punctiformis (Pers.) R. C. Harris – KvR: 1, 3. KvR!

Nephroma bellum (Spreng.) Tuck. – KvR, KzR, VNP: 1–4. RK.

Nephroma laevigatum Ach. – KvR: 3; VNP: 4. *Kton*! VNP! RK.

Nephroma parile (Ach.) Ach. – KvR, KzR, Ptz, VNP: 1–4.

Nephroma resupinatum (L.) Ach. – KvR, KzR, VNP: 2–4.

Ochrolechia alboflavescens (Wulfen) Zahlbr. – KvR: 1; Ptz: 1, 2. KzR! The specimens contain variolaric, lichesterinic and protolichesterinic acids.

Ochrolechia arborea (Kreyer) Almb. – KzR: 1. KzR! The specimens contain lichexanthone, gyrophoric and lecanoric acids.

Ochrolechia bahusiensis H. Magn. – KvR, KzR, Ptz, VNP: 1–4.The specimens contain gyrophoric, lecanoric acids and murolic acid complex. The species recently was found in Karelia (Tarasova & Stepanchikova, 2016; Tarasova et al., 2016a).

Ochrolechia mahluensis Räsänen – KvR: 1; Ptz: 3. Ptz! The specimens contain gyrophoric and lecanoric acids. The species was only known in Karelia fromVodlozero National Park (*Kton*) (Kukwa, 2011) and Kivach Strict Nature Reserve (*Kon*) (Tarasova et al., 2016b).

Ochrolechia pallescens (L.) A. Massal. – KvR, KzR, VNP: 1–4. KzR!

Opegrapha niveoatra (Borrer) J. R. Laundon – KzR: 2, 3. *Kon*! KzR! The species was reported from Karelia without exact locality (Kopaczevskaja et al., 1977).

Opegrapha vulgata (Ach.) Ach. – KzR: 3. *Kon*! KzR!

Pachyphiale fagicola (Arnold) Zwackh – KvR, KzR, Ptz, VNP: 1–4. *Kton*! VNP!

Parmelia sulcata Taylor – KvR, KzR, Ptz, VNP: 1–4.

Parmeliella triptophylla (Ach.) Müll. Arg. – KvR, KzR, VNP: 1–3. *Kton*! KzR! VNP!

Parmeliopsis ambigua (Wulfen) Nyl. – KvR, KzR, Ptz, VNP: 1–4.

Parmeliopsis hyperopta (Ach.) Arnold – KvR, KzR, Ptz, VNP: 1–3.

Peltigera canina (L.) Willd. – KvR, KzR, Ptz: 2, 3. Conf. O. Vitikainen.

Peltigera degenii Gyeln. – KvR: 2. KvR! Conf. O. Vitikainen.

Peltigera leucophlebia (Nyl.) Gyeln. – KvR, KzR, Ptz: 2, 3. Conf. O. Vitikainen.

PELTIGERA NECKERI Hepp ex Müll. Arg. – KvR, Ptz: 1–3. Conf. O. Vitikainen.

PELTIGERA NEOPOLYDACTYLA (Gyeln.) Gyeln. – KvR: 2, 3. Conf. O. Vitikainen.

PELTIGERA POLYDACTYLON (Neck.) Hoffm. – KzR: 3. Conf. O. Vitikainen.

PELTIGERA PRAETEXTATA (Flörke ex Sommrerf.) Zopf – KvR, KzR, Ptz, VNP: 1–4. Conf. O. Vitikainen.

PELTIGERA RUFESCENS (Weiss) Humb. – KvR: 2. Conf. O. Vitikainen.

PERTUSARIA ALBESCENS (Huds.) M. Choisy & Werner – KvR, KzR: 3. The specimens contain fatty acids.

PERTUSARIA AMARA (Ach.) Nyl. – KvR, KzR, Ptz, VNP: 1–4.

PERTUSARIA COCCODES (Ach.) Nyl. – KzR: 1, 3; VNP: 4. *Kon*! KzR!

PERTUSARIA LEIOPLACA DC. – KvR: 1, 2; VNP: 4. VNP!

+PHAEOCALICIUM POPULNEUM (Brond. ex Duby) A. F. W. Schmidt – Ptz: road to Barany Bereg village, ca. 2 km of Onega lake, 61°50.472'N, 34°30.482'E, 3. The species was known from *Ks* (Fadeeva et al., 2007) and *Kon* provinces (Tarasova et al., 2016a). RK.

PHAEOPHYSCIA CILIATA (Hoffm.) Moberg – KvR, KzR, Ptz, VNP: 1–4.

PHLYCTIS ARGENA (Ach.) Flot. – KvR, KzR, Ptz, VNP: 1–4.

PHYSCIA ADSCENDENS (Fr.) H. Olivier – KvR, KzR, VNP: 1, 2. *Kton*! VNP!

PHYSCIA AIPOLIA (Ehrh. ex Humb.) Fürnr. – KvR, KzR, Ptz, VNP: 1–4.

PHYSCIA ALNOPHILA (Vain.) Loht. et al. – KvR, KzR, Ptz, VNP: 1–4.

PHYSCIA STELLARIS (L.) Nyl. – VNP: 1–4.

PHYSCONIA DETERSA (Nyl.) Poelt – VNP: 2. *Kton*! VNP!

PHYSCONIA DISTORTA (With.) J. R. Laundon. – Ptz: 1; VNP: 1, 4. VNP!

PHYSCONIA PERISIDIOSA (Erichsen) Moberg – KzR: 1, 3.

PICCOLIA OCHROPHORA (Nyl.) Hafellner – VNP: Bostilovo, 61°12.001'N, 36°51.114'E, 1; 61°11.972'N, 36°51.009'E, 2. *Kton*! VNP! The species was only known in Karelia from historical collection of the XIX century in Petrozavodsk (Tarasova et al., 2015).

PLACYNTHIELLA ICMALEA (Ach.) Coppins & P. James – KzR: 1.

PLATISMATIA GLAUCA (L.) W. L. Culb. & C. F. Culb. – KvR, KzR, Ptz, VNP: 1–3.

PSEUDOSCHISMATOMMA RUFESCENS (Pers.) Ertz & Tehler – KvR, KzR: 2. KzR!

RAMALINA FARINACEA (L.) Ach. – KvR, KzR, Ptz, VNP: 1–3.

RAMALINA SINENSIS Jatta – KvR, KzR, Ptz, VNP: 2–4. VNP!

RAMALINA THRAUSTA (Ach.) Nyl. – KvR: 2; VNP: 4. RK.

RINODINA EXIGUA (Ach.) Gray – Ptz: 3.

RINODINA PYRINA (Ach.) Arnold – KvR: 2; VNP: 1. KvR!

RINODINA SEPTENTRIONALIS Malme – KvR: 2; KzR: 2; VNP: 4. *Kton*! KvR! KzR! VNP!

ROPALOSPORA VIRIDIS (Tønsberg) Tønsberg – KzR: 1; Ptz: 2.KzR! The specimens contain perlatolic acid. The species was only known from Kivach Reserve (*Kon*) (Hermansson et al., 2002) and Petrozavodsk (*Kol*) (Tarasova et al., 2016a).

ROSTANIA OCCULTATA (Baglietto) Otálora, P. M. Jørg. & Wedin – VNP: 4. VNP! RK.

SCOLICIOSPORUM CHLOROCOCCUM (Graewe ex Stenh.) Vězda – VNP: 2.

SCYTINIUM SUBTILE (Schrad.) Otálora et al. – KvR: 2, 3. RK.

SCYTINIUM TERETIUSCULUM (Wallr.) Otálora et al. – KvR, KzR, Ptz, VNP: 2–4. KzR!

STENOCYBE PULLATULA (Ach.) Stein – VNP: 1. VNP!

STRANGOSPORA MORIFORMIS (Ach.) Stein – KvR: 2, 3. KvR!

TOENSBERGIA LEUCOCOCCA (R. Sant.) Bendiksby & Timdal – Ptz: 3.

USNEA BARBATA (L.) Weber ex F. H. Wigg. – KvR: 2. *Kon*! KvR! RK.

USNEA DASOPOGA (Ach.) Nyl. – VNP: 3.

USNEA SUBFLORIDANA Stirt. – KzR, VNP: 1; Ptz: 1, 3.

VULPICIDA PINASTRI (Scop.) J.-E. Mattsson & M. J. Lai – KvR, KzR, Ptz, VNP: 1–4.

XANTHORIA PARIETINA (L.) Th. Fr. – KvR, KzR, VNP: 1–3.

**b. Liverworts**

BLEPHAROSTOMA TRICHOPHYLLUM (L.) Dumort. – KvR, KzR, Ptz, VNP: 1–4.

CALYPOGEIA MUELLERIANA (Schiffn.) Müll. Frib. – KvR, KzR: 2, 3.

LEJEUNEA CAVIFOLIA (Ehrh.) Lindb. – KzR: 2. KzR! *Kon!* RK.

LIOCHLAENA LANCEOLATA Nees – KvR, KzR, VNP: 2–4. VNP!

LOPHOCOLEA HETEROPHYLLA (Schrad.) Dumort. – KvR, KzR, Ptz, VNP: 1–4. VNP! *Kton!*

Lophozia guttulata (Lindb. & Arnell) A. Evans – KzR, VNP: 3, 4. KzR! VNP! *Kton!*

Lophozia silvicola H. Buch – KvR, KzR: 3. KzR! *Kton!*

Lophoziopsis longidens (Lindb.) Konstant. & Vilnet – KvR, KzR: 1–3. KvR!

Neoorthocaulis attenuatus (Mart.) L. Söderstr., De Roo & Hedd. – KvR, KzR, Ptz, VNP: 1, 2.

Plagiochila porelloides (Torr. ex Nees) Lindenb. – KvR, KzR, VNP: 1–4. VNP!

Ptilidium pulcherrimum (Weber) Vain. – KvR, KzR, Ptz, VNP: 1–4.

Radula complanata (L.) Dumort. – KvR, KzR, Ptz, VNP: 1–4.

### c. Mosses

Abietinella abietina (Hedw.) M. Fleisch. – KzR: 1.

Amblystegium serpens (Hedw.) Schimp. – KzR: 1–3.

Brachytheciastrum velutinum (Hedw.) Ignatov & Huttunen – KvR: 3; Ptz: 2, 3; KzR: 3; VNP: 2. KzR! VNP!

Brachythecium salebrosum (Hoffm. ex F. Weber & D. Mohr) Schimp. – KvR, KzR, Ptz, VNP: 1–4.

Breidleria pratensis (W. D. J. Koch ex Spruce) Loeske – KvR: 3; KzR: 2. KzR!

Bryum moravicum Podp. – KzR: 2. *Kon!* KzR!

Climacium dendroides (Hedw.) F. Weber & D. Mohr – KvR: 3, Ptz: 3.

Dicranum montanum Hedw. – KzR: 1.

Dicranum scoparium Hedw. – KvR, KzR, Ptz, VNP: 1–4.

Eurhynchiastrum pulchellum (Hedw.) Ignatov & Huttunen – KvR: 1–3.

Fissidens adianthoides Hedw. – Ptz: 3.

Heterocladium dimorphum (Brid.) Schimp. – KzR: 3.

Homalia trichomanoides (Hedw.) Brid. – Ptz: 1.

Hylocomium splendens (Hedw.) Schimp. – KvR, KzR, Ptz, VNP: 1–4.

Mnium stellare Hedw. – KvR, KzR, VNP: 1–4.

Neckera pennata Hedw. – KvR, KzR, VNP: 2; Ptz: 3. KzR! RK.

Orthotrichum obtusifolium Brid. – KvR 3.

Orthotrichum speciosum Nees – KvR, KzR, Ptz: 1–3; VNP: 1, 2.

Plagiomnium cuspidatum (Hedw.) T. J. Kop. – KvR, VNP: 2, 3; KzR: 1, 2; Ptz: 1–3.

Plagiomnium drummondii (Bruch & Schimp.) T. J. Kop. – VNP: 2. *Kton!* VNP! RK.

Plagiothecium laetum Schimp. – KvR: 1; KzR: 3.

Pleurozium schreberi (Willd. ex Brid.) Mitt. – KvR, KzR: 1–3; Ptz: 2, 3; VNP: 2.

Pseudoleskeella tectorum (Funck ex Brid.) Kindb. ex Broth. – KzR: 1. KzR!

Pylaisia polyantha (Hedw.) Schimp. – KvR, KzR, Ptz, VNP: 1–4.

Rhizomnium punctatum (Hedw.) T. J. Kop. – Ptz: 2.

Rhodobryum roseum (Hedw.) Limpr. – KvR: 1, 3; KzR: 1; Ptz, VNP: 2.

Rhytidiadelphus triquetrus (Hedw.) Warnst. – KvR, KzR, Ptz, VNP: 1–4.

Sanionia uncinata (Hedw.) Loeske – KvR, KzR, Ptz, VNP: 1–4.

Sciuro-hypnum reflexum (Starke) Ignatov & Huttunen – KzR: 3;VNP: 1.

Serpoleskea subtile (Hedw.) Schimp. – KvR, KzR, Ptz, VNP: 1–4.

Tetraphis pellucida Hedw. – KzR: 3.

Thuidium recognitum (Hedw.) Lindb. – KvR, Ptz: 2, 3; KzR: 2.

## RESULTS AND DISCUSSION

A total of 222 species (excluding free-living algae and cyanobacteria) were recorded on 192 aspen trees in an area of 24 ha in the middle boreal forest communities in the Republic of Karelia, including 178 lichens and allied fungi, 32 mosses and 12 liverworts.

### Lichen diversity

Species composition of lichen communities growing on aspen trees is traditionally highly diverse (Kuusinen, 1994; Pystina & Hermansson, 1996; Ohlson et al., 1997). Study of lichens growing on aspen has greatly expanded our understanding of the biota and their distribution in the study area. Three recorded species - *Arthonia biatoricola*, *A. excipienda*, and *Biatoridium monasteriense* - are new for the Republic of Karelia. Seven species are new for the biogeographical province *Karelia olonetsensis*; 17 - for *Karelia onegensis* and 39 - for *Karelia transonegensis*. Some lichen species were found in the studied areas for the first time: two species in Petrozavodsk City, 31 – in the Kivach Strict Nature Reserve, 45 – in the Kizhi Sanctuary and 51 – in the Vodlozero National Park.

Eighteen indicator species of old-growth boreal forests were recorded (Andersson et al., 2009) – *Acrocordia gemmata*, *Arthonia vinosa*, *Chaenotheca brachypoda*, *C. chlorella*, *C. gracilenta*, *C. laevigata*, *C. stemonea*, *Gyalecta truncigena*, *Leptogium saturninum*, *Lobaria pulmonaria*, *Nephroma bellum*, *N. laevigatum*, *N. parile*, *N. resupinatum*, *Parmeliella triptophylla*, *Pertusaria coccodes*, *Ramalina thrausta* and *Scytinium teretiusculum*. Fifteen lichen species recorded in the studied communities associated with aspen are listed in the Red Data Book of Republic of Karelia (2007): *Anaptychia ciliaris*, *Arthonia vinosa*, *Bryoria nadvornikiana*, *Chaenotheca gracilenta*, *C. stemonea*, *Lecidea albofuscescens*, *Lobaria pulmonaria*, *Melanelixia subaurifera*, *Nephroma bellum*, *N. laevigatum*, *Phaeocalicium populneum*, *Ramalina thrausta*, *Rostania occultata*, *Scytinium subtile* and *Usnea barbata*.

Crustose lichens dominated on aspen trees (105 species), contributing 59% of the total number of lichen species. Forty-five foliose (25%) and 28 fruticose (16%) lichen species were recorded on aspen trees. The epiphytic cover of aspen was dominated by true epiphytes – 147 species (83%). There were also 17 muscicolous (10%) species, the remaining 7% being represented by lignicolous (6 species), multi-substrate (5 species) and terricolous (3 species) lichens.

**Bryophyte diversity**

*Populus tremula* is characterized by supporting the highest number of epiphytic bryophyte species in Nordic countries (Hazell et al., 1998; Snäll et al., 2004) and Latvia (Mežaka et al., 2008, 2010). Most collected bryophytes were common species in Karelia. However, two species were recorded as new for the biogeographical province *Karelia olonetsensis* and four – for *Karelia transonegensis.* Three liverworts (*Lejeunea cavifolia*, *Lophozia guttulata* and *L. silvicola*) and five bryophytes (*Brachytheciastrum velutinum*, *Breidleria pratensis*, *Bryum moravicum*, *Neckera pennata* and *Pseudoleskeella tectorum*) are new for the Kizhi Sanctuary. Five species of liverworts (*Liochlaena lanceolata*, *Lophocolea heterophylla*, *Lophozia guttulata*, *L. silvicola* and *Plagiochila porelloides*) and two moss species (*Brachytheciastrum velutinum* and *Plagiomnium drummondii*) were found for the first time in the Vodlozero National Park. In the present study, *Lejeunea cavifolia* was registered for the third time in Karelia. This species was collected in mixed aspen-spruce forest in the Kizhi Sanctuary. *Lejeunea cavifolia* is a nemoral liverwort with a predominantly circumpolar distribution, rather frequent in Russia (Konstantinova et al., 2009). Previously, *Lejeunea cavifolia* was recorded in the Republic of Karelia from *Karelia ladogensis* (Arnell, 1956) and Paanajarvi National Park (Auer, 1944).

Eight indicators of old-growth and virgin boreal forests (Andersson et al., 2009) were recorded in our study – *Lejeunea cavifolia*, *Liochlaena lanceolata*, *Neoorthocaulis attenuates*, *Eurhynchiastrum pulchellum*, *Homalia trichomanoides*, *Mnium stellare*, *Neckera pennata* and *Orthotrichum obtusifolium*. Three bryophyte species (*Neckera pennata*, *Plagiomnium drummondii* and *Lejeunea cavifolia*) listed in the Red Data Book of Karelia Republic (2007) were found.

Six basic life forms (i.e. growth forms) according to K. Mägdefrau (1982) and J. Glime (2007) – wefts, turfs, mats, fans, cushions and dendroids – have been found for aspen bryophytes. Furthermore, the interbryophyte life form is added to liverworts (Borovichev, 2011). In our research, most moss species belonged to wefts life form (16 species), tall turfs (4) and short turfs (3). Among the liverworts collected on aspen, the most common types of growth forms were interbryophytes (10 species) and mats (6). The greatest number of species generate several life forms adapted to different microhabitat conditions (Mägdefrau, 1982; Andrejeva, 1990; Borovichev, 2011). Amongst bryophytes recorded on aspen all substrate groups of mosses can be found – epiphytic (5), epixylic (3), epigeic (6), epilytic (4), multisubstrate (14) species. The highest number of aspen liverworts was found at the base of trees represented by multisubstrate species (9); only three species were generally epiphytes (or rare epixyles).

**The influence of habitat on the cryptogamic communities associated with aspen**

The study has revealed differences in the species composition of epiphytes on aspen trunks and branches due to distinct differences in habitat conditions within a single tree. Thus, the species composition of lichens living in the lower part of the trunk and on branches (in the crown) varied significantly: 161 species were registered on the trunk, and 64 – on branches. Unlike lichens, mosses in the aspen crown were almost absent, except for the *Orthotrichum* species (*O. speciosum* and *O. obtusifolium*).

The epiphytic cover was also quite heterogeneous in the lower part of the trunk (0–2 m). At the base of aspen trees (0–25 cm), cryptogamic cover was better developed: the mean total coverage was over 70%, with mosses accounting for more than 84% of the coverage and lichens for only 16% (Table 2). The most common bryophyte species were wefts, turfs and interbryophytes, such as *Hylocomium splendens*, *Liochlaena lanceolata*, *Lophozia guttulata*, *L. silvicola*, *Lophoziopsis longidens*, *Mnium stellare*, *Neoorthocaulis attenuatus*, *Plagiomnium cuspidatum*, *Plagiochila porelloides*, *Rhytidiadelphus triquetrus* preferring tree bases and not epiphytes in a narrow sense. These species are generally epigeic, growing on soil. Few lichens were present surrounded by fast-growing large organisms (mosses and liverworts). For example, *Mycobilimbia* and *Peltigera* species possess the ability to grow on the surface of moss clumps.

At the height of 1.3 m above ground level, the average overall coverage is significantly lower (on average, only 38%), with lichens contributing 61% and mosses and liverworts – 39% (Table 2). The occurrence of true epiphytes (*Lejeunea cavifolia*, *Neckera pennata*, *Orthotrichum obtusifolium*, *O. speciosum* and *Radula complanata*) was maximum at levels higher than 1.3 m on the tree trunk. At a height of 1.3 m above ground level, the humidity might be lower than at the base of the trunk, therefore the competition between mosses and lichens may decrease and consequently the diversity and coverage of lichens increase.

**Table 2.** Average values of the main characteristics of epiphytes (lichens and bryophytes) on aspen tree trunks in the middle boreal forests of Republic of Karelia. Differences between groups were tested by Mann–Whitney one-way analysis of variance at 99.9% significance level (***); [1]dominant taxa are species or species groups with a cover more than 1%; [2]treatment of the genus *Mycobilimbia* was according to Urbanavichus (2010); [3]including *Brachytheciastrum velutinum*, *Sanionia uncinata*, and *Pylaisia polyantha*.

| Characteristics | Height at above ground, m | | *U*-test | Proportion of species in total cover, % | |
|---|---|---|---|---|---|
| | 0 m | 1.3 m | | 0 m | 1.3 m |
| Total cover, % | 73.0±1.02 | 37.72±0.91 | *** | 100 | 100 |
| Cover of bryophytes, % | 61.57±1.10 | 14.75±0.66 | *** | 84 | 39 |
| Cover of lichens, % | 11.43±0.57 | 22.97±0.76 | *** | 16 | 61 |
| Number species, no. | 4.51±0.08 | 4.81±0.09 | – | – | – |
| Number species of bryophytes, no. | 1.65±0.05 | 1.46±0.04 | – | – | – |
| Number species of lichens, no. | 1.85±0.06 | 3.36±0.09 | *** | – | – |
| Cover of dominant species and groups of species[1], %: | | | | | |
| *Cladonia* spp. | 1.67±0.19 | 0.42±0.09 | *** | 2 | 1 |
| *Lecanora* spp. | 0.02±0.01 | 1.76±0.18 | *** | 0.3 | 4 |
| *Mycobilimbia* spp.[2] | 4.54±0.35 | 2.94±0.32 | *** | 6.2 | 8 |
| *Nephroma* spp. | 0.51±0.10 | 0.53±0.12 | – | 0.7 | 1 |
| *Peltigera* spp. | 2.90±0.36 | 0.07±0.04 | *** | 4 | 0.2 |
| *Hypogymnia physodes* | <0.01 | 1.15±0.19 | *** | 0 | 3 |
| *Lobaria pulmonaria* | 0.36±0.11 | 3.59±0.34 | *** | 0.5 | 10 |
| *Phlyctis argena* | 0.67±0.16 | 7.63±0.52 | *** | 0.9 | 20 |
| *Brachythecium salebrosum*[3] | 21.19±0.97 | 7.96±0.44 | *** | 30 | 21 |
| *Radula complanata* | 2.95±0.23 | 4.18±0.36 | – | 4 | 11 |
| *Hylocomium splendens* | 8.16±0.69 | 0.14±0.06 | *** | 11 | 0.3 |
| *Rhytidiadelphus triquetrus* | 12.92±0.97 | 0.24±0.10 | *** | 18 | 0.6 |
| *Mnium stellare* | 4.63±0.51 | 0.17±0.12 | *** | 6 | 0.5 |
| *Plagiomnium cuspidatum* | 4.46±0.56 | 0.01±0.01 | *** | 6 | 0 |
| *Serpoleskea subtile* | 1.65±0.32 | 0.10±0.06 | *** | 2 | 0.3 |

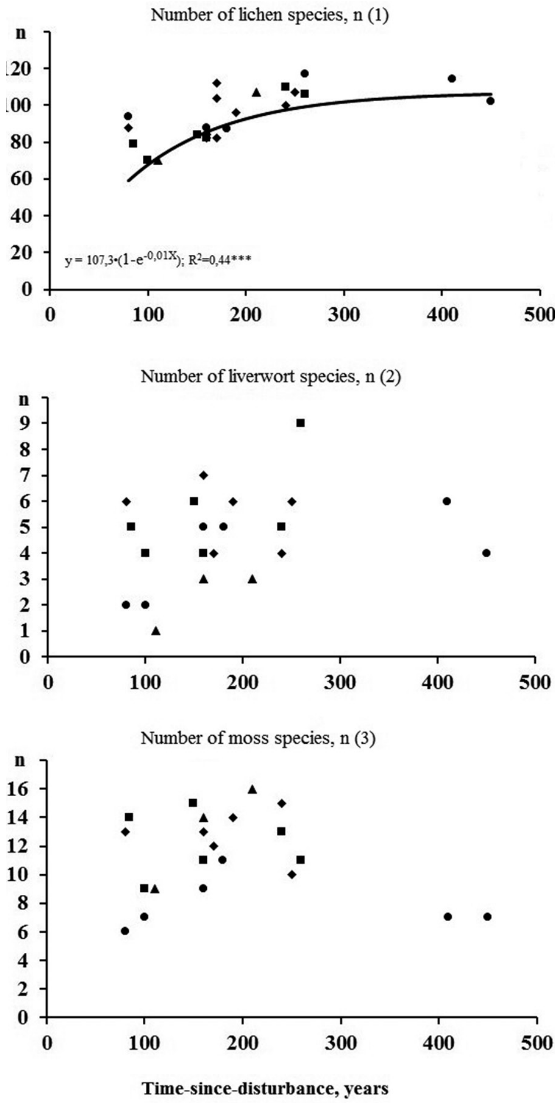


**Fig. 2.** The number of lichens, lichenicolous, non-lichenized fungi (1), liverwort (2) and moss (3) species on aspen per 1 ha in middle boreal forests at different time-since-disturbance (southern Karelia). The study areas are marked by the following figures: ▲ – Petrozavodsk City, ■ – Kizhi Sanctuary, ● – Vodlozero National Park, ◆ – Kivach Strict Nature Reserve. P – value of regression coefficient (R) is less than the significance level, such as 0.001 (***).

Lichen diversity depended on the time-since-disturbance of the community (Fig. 2). The total number of lichens on aspen increased on average from 40 to 60 species per ha with the increase of the time since disturbance from 100 to 450 years (Fig. 2.1). Stabilization is observed at about 200 years since disturbance (Fig. 2.1). In the earlier successional stages, at 80 years since disturbance, the total lichen species diversity on aspen is richer by 10–20 species as compared with that at 100–160 years since disturbance. Perhaps this might be due to changes-from smooth to rough aspen bark, as well as to changes in light and moisture conditions as the proportion of spruce increases in the stand and the epiphyte community of young aspen trees changes into the epiphyte community of middle-aged trees. Lichen species inhabiting early successional habitats belonged to the following genera: *Buellia*, *Caloplaca*, *Evernia*, *Lecanora*, *Melanelixia*, *Melanohalea*, *Physcia*, *Physconia*, *Ochrolechia*, and the species *Fuscidea pusilla*, *Hypogymnia physodes*, *Leptogium saturninum*, *Xanthoria parietina.* Late-successional species are *Lobaria pulmonaria*, *Lopadium disciforme*, *Nephroma* spp., *Pertusaria albescens*, *P. coccodes*, *Rostania occultata*, calicioid lichens (*Chaenotheca brachypoda*, *C. chlorella*, *C. gracilenta*, *C. laevigata*,*C. stemonea* and *C. hispidula*) and calicioid fungi (*Chaenothecopsis vainioana* and *Phaeocalicium populneum*). It is noteworthy that with the increase of time-since-disturbance and decrease in the number of aspen trees (Table 1) as a result of their decay in all studied forests, the lichen diversity on aspen in the communities did not decrease and remained constantly high.

For a large group of lichen species, there is no correlation between frequency of their occurrence and the time after community disturbance (see list of lichens). Typically, these were dominant and widespread species, such as *Anisomeridium polypori*, *Bacidia subincompta*, *Biatora albohyalina*, *B. efflorescens*, *B. helvola*, *B. ocelliformis*, *Lecania naegelii*, *Lecanora allophana*, *Lepraria jackii*, *Mycobilimbia carneoalbida*, *M. epixanthoides*, *M. tetramera*, *Parmelia sulcata*, *Parmeliopsis ambigua*, *Peltigera praetextata*, *Phlyctis argena* and *Vulpicida pinastri.*

No significant correlation between bryophyte diversity on aspens and the time-since-disturbance was found in our study (Fig. 2.2, 2.3).

This result is in accordance with previous research (Mežaka & Znotiņa, 2006; Mežaka et al., 2012; Putna & Mežaka, 2014). This might arise, however, by the low number of mosses and liverworts in sample plots characterized by relatively short time after disturbance (80–100 years). Most species of aspen bryophytes were found in communities at later successional stages. The species *Abietinella abietina*, *Bryum moravicum*, *Dicranum montanum* and *Pseudoleskeella tectorum* were only found in young forests with a time from disturbance of 80–110 years. These species are not strictly epiphytes and grow often on other substrates (Ignatov & Ignatova, 2003, 2004). At the same time, species that are used as indicators of old-growth boreal forests, such as *Homalia trichomanoides*, *Neckera pennata* and *Orthotrichum obtusifolium*, were found only in communities with time after disturbance of more than 110 years.

Six liverworts – *Blepharostoma trichophyllum*, *Lophocolea heterophylla*, *Lophozia guttulata*, *Lophoziopsis longidens*, *Ptilidium pulcherrimum* and *Radula complanata* were recorded at earlier stages of succession (80–110 years). In old-growth forest, six liverworts were found too – *Liochlaena lanceolata*, *Lophocolea heterophylla*, *Lophozia guttulata*, *Plagiochila porelloides*, *Ptilidium pulcherrimum* and *Radula complanata*.

Aspen in southern Karelia is characterized by having a high diversity of epiphytes and plays a significant role in maintaining the diversity and conservation of rare species, especially lichens. Higher humidity could create optimal conditions for the development of bryophyte cover on the aspen trunks. Therefore, lichens and mosses on the trunks of aspen often occupy different ecological niches.

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