

Ecological preferences and abundances of populations of protected lichens in linden forests on the Salair Ridge in Altai Territory

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For a comprehensive assessment of the habitats of rare and vulnerable lichen species, the *Tilia sibirica* forest in the Zarinsky Districts of the Altai Territory was studied. Plant communities were described on 25 sample plots. Seven species of lichens listed in the Red data book of the Altai Territory were found in the studied forests: *Graphis scripta*, *Heterodermia speciosa*, *Lobaria pulmonaria*, *Nephroma bellum*, *Ramalina roesleri*, *R. sinensis*, and *R. vogulica*. New quantitative data on cenopopulations of the studied lichen species in Salair region have been obtained. Ecological preferences are indicated for each species and the abundance of populations (dm²/ha) are calculated. Linden forest is shown to have a high conservation value regarding lichens.

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Introduction

The Salair botanical-geographical area (Salair and Predsalairye, Silantieva, 2013) is a relatively poorly lichenologically studied region of the Altai Territory, for which only about one hundred species of lichens are known (Davydov 1999, 2004; Davydov 2014; Davydov and Konoreva 2017; Konoreva et al. 2016; Stas' 1999; Vondrák et al. 2016, 2019; Davydov et al. 2022).

The actual edition of the Red Data Book of the Altai Territory includes 23 species of lichens (Davydov 2016), and 8 of them were recorded for Salair Ridge recently (Davydov et al. 2020; 2022).

IUCN suggests using quantitative population parameters for maintaining Red Lists, the same is recommended for the preparation and maintenance of national and regional Red Books.

To assess the sustainability of the species, as well as to develop strategy for its conservation, it is necessary to reveal factors determining its distribution at different spatial scales: from the cenopopulation to the entire distribution area. Studies of the magnitude and structure of lichen populations in different environmental conditions can shed light on the causes of substrate and phytocenotic confinement of lichens (Gauslaa 1997; Rhoades 1983), as well as on the population mechanisms of their resistance/sensitivity to anthropogenic influence (Mikhailova and Vorobeitchik 1999; Suetina 2001). Understanding the composition, abundance and structure of populations of rare and endangered lichen species is a necessary basis for assessing their current status and developing a conservation strategy (Istomina, 1996; Scheidegger, Goward, 2002; Mikryukov et al. 2010; Ignatenko and Tarasova, 2017, 2018, 2020). There are only few works containing quantitative information on lichens of the Altai Territory (Davydov 1999, 2008; Davydov et al. 2020).

Our on-going project aimed to reveal the distribution, biology and ecology of protected lichens in Salair botanical-geographical area of the Altai Territory and to estimate a abundance of its populations. Here we present the results of our investigations of cenopopulations of protected lichens in *Tilia sibirica* forests in the Salair National Park – the only locality of *Tilia sibirica* in Altai Territory (Bykov et al. 2021; Zyablintseva et al. 2022).

Siberian lime (*Tilia sibirica* Bayer) is a broad-leaved deciduous tree closely related to European *Tilia cordata* Mill. It is endemic to a few sites in southern Siberia, located approximately 2000 km east of the limit of the European deciduous forest biomen (Novák et al. 2014). *Tilia sibirica* is the only nemoral forest-forming species in Siberia; it is a tertiary relict which preserved from ancient times in Salair on a limited territory (Polozhiy and Krapivkina 1985). *Tilia sibirica* forests are among the rare plant communities in the Altai Territory, as well as in the whole of Siberia (Gudoshnikov 1986; Krapivkina 1996; Maleev 1949) and the information about linden forests in the Altai Territory is very scarce (Elesova 2018; Ermakov 1995; Khlonov 1965; Silantieva 2013; Terekhina and Kopytina 2016).

The Salair linden forest is located on the southern macroslope of the Salair ridge, in the basin of the Togul River. According to the geobotanical zoning of the Altai Territory (1958), the research area belongs to the belt of subnemoral chern' forests of Salair, the area of aspen and fir-aspen forests on gray forest and deep-saline soils of the Salair plateau. Within the Salair ridge, this site belongs to the Zapadno-Chumyshsky Natural Area (Laschinsky, 2009). The relief of the research area is represented by smoothed elevations, heights range from 297 to 344 m a. s. l. The average annual precipitation in this area is 400-600 mm, with a maximum in summer. The length of the growing season is 145-175 days, the frost-free period is 65-120 days. In terms of heat supply, the district belongs to the moderately cool: the sum of temperatures above 10°C it is 1880 degrees. The vegetation of the area is characterized by a wide spread of subnemoral chern' forests forests, where *Abies sibirica* Ledeb. and *Populus tremula* L. are the dominant trees (Laschinsky, 2009).

Materials and Methods

For a comprehensive assessment of the habitats of rare and vulnerable lichen species, the linden forest in the Zarinsk District of the Altai Territory was studied. Linden Forest is located on the southern mountainside of the Salair Ridge in the watershed of the Togul River at the 13 km to NE from the Novoiushino. The landscape is represented by smoothed elevations, the heights range from 297 to 344 m above sea level. The plot of about 60 hectares is the only array of linden forests on the Salair Ridge. The total area of the *Tilia sibirica* population in the Altai Territory is about 2 square kilometers. Old-growth forests, which have never been cut down were the focus of the present investigation.

Twenty five 400 square meters sample plots were at 100–200 m distance from each other to make more or less uniform network. Plant communities were described on each plot. To estimate the age of linden trees, 15 thickest trees were randomly selected and drilled by increment borer at the altitude 130 cm in two directions each.

To estimate the abundance of populations of protected lichen the projective cover of every species were ocularly evaluated on every tree trunk higher than 3 m at height from 0 to ca. 3–4 m on all sides of the trunk with an accuracy ca. 10 cm². For single or few thalli on the trunk the accuracy was ca. 1 cm². We did not use a geobotanical grid to increase the accuracy because it is time consuming and excessive for our abundance estimation. Fallen trees were investigated from the base to the crown to estimate the distribution of lichen thalli higher than 3 m.

Voucher specimens of every species of protected lichen were collected by authors and deposited in the herbarium of the Altai State University (ALTB). Morphological observations were made using a stereomicroscope Zeiss Stemi 2000-C. Cross-sections of apothecia and thalli were made by hand with a razor blade and observed with a Zeiss Axio Lab.A1 compound microscope after mounting in water. Lichen substances of some species were studied by spot-tests using potassium hydroxide solution (K), sodium hypochlorite solution (C), 1,4-p-phenyldiamine (PD), and iodine (I) (Orange et al. 2001).

Results

In accordance with the objectives of the study, forests with predominance in the linden stand were studied (Fig. 1). Both pure linden forests and forests with the participation of fir and aspen have been studied. Tree species ratio (stand formula) was *Tilia*(10), *Tilia*(10)-*Abies*(+), *Tilia*(10)-*Populus*(+), *Tilia*(10)-*Abies*(+)-*Betula*(+), *Tilia*(9)-*Populus*(1), *Tilia*(8)-*Abies*(2), *Tilia*(8)-*Populus*(2)-*Abies*(+).

Tree layer is usually composed of two sublayers, less often single layer and formed by *Tilia sibirica* Bayer, *Populus tremula* L., and *Abies sibirica* Ledeb. The forest is dense, moist enough; the cover of the tree layer is 70–80%, with a maximum of 90%. The average age of the *Tilia sibirica* is 71 years (55–84 years), average diameter of the trunk is 23 cm, and the maximum one is 45 cm. The undergrowth includes *Abies sibirica*, *Tilia sibirica*, and *Sorbus sibirica* Nakai.

The cover of the shrub layer is 3–10%. *Caragana frutex* (L.) C. Koch, *Ribes atropurpureum* C.A. Mey. are dominated. *Lonicera xylosteum* L., *Sambucus sibirica* Nakai, *Rubus idaeus* L., *Spiraea chamaedryfolia* L. are less common, sometimes the shrub layer is absent.

The grass layer consists of two or three sublayers, the average cover is 65% and the maximum one is 85%. The main dominants of high grass (first and second sublayer) are *Crepis sibirica* L., *Matteuccia struthiopteris* (L.) Tod., *Aegopodium podagraria* L., *Aconitum septentrionale* Koelle, *Festuca altissima* All., *Urtica dioica* L., *Pleurospermum uralense* Hoffm. The third sublayer is formed by *Asarum europaeum* L., *Oxalis acetosella* L., *Cerastium pauciflorum* Steven ex Ser. Vascular spore plants represented by *Equisetum sylvaticum* L., *Matteuccia struthiopteris*(L.) Tod., *Polystichum braunii* (Spenn.) Feé, *Dryopteris filix-mas* (L.) Schott, *D. expansa* (C. Presl) Fraser-

Jenkins et Jermy, *Athyrium monomachii* (Kom.) Kom., *A. sinense* Rupr., *A. filix-femina* (L.) Roth ex Mert., *Pteridium aquilinum* (L.) Kuhn.

Fifty six species of higher plants were recorded on an area of 400 m², among which were several tertiary relics. These are eight species of grass – *Asarum europaeum*, *Asperula odorata* L., *Festuca altissima*, *F. gigantea* (L.) Vill., *Myosotis krylovii* Serg., *Paeonia anomala* L., *Stachys sylvatica* L., *Dryopteris filix-mas*, *Polystichum braunii*, and one tree – *Tilia sibirica*. The early spring flora of the linden forests of the Altai Territory is represented by *Erythronium sibiricum* Fisch. et C. A. Mey.) Krylov, *Anemone altaica* Fisch. et C. A. Mey., *A. caerulea* DC., *Corydalis bracteata* Pers., *Ranunculus monophyllus* Ovcz., *Viola uniflora* L., and *Gagea granulosa* Turcz.

Five fallen trees were investigated from the base to the crown to estimate the distribution of lichen thalli higher than 3 m. Fortunately, the absolute majority of target lichens grows at the basic part of trunk at the altitude between 1 and 3(4) m. This is most favorable part of tree for light-loving species of *Ramalina*. The altitude 0-1 m is often in a shade of herbs, ferns, undergrowth and shrubs. Crowns of linden trees are developed in the upper quarter of the trunks, forming a dense canopy. *Graphis scripta*(L.) Ach. grows mostly at the altitude 0-2 m, *Heterodermia speciosa* (Wulfen) Trevis., *Lobaria pulmonaria*(L.) Hoffm., *Nephroma bellum*(Spreng.) Tuck. at the same altitude, but over mosses.

Five potential phorophytes were examined (Table 1). The majority of *Tilia sibirica* trees were over 10 cm in diameter with rough cracked bark. Only few *Abies sibirica* trees were in the tree layer, most of them grow in undergrowth and have diameter of trunk about 4-10 cm. *Sorbus sibirica* also grow in undergrowth, some of trees were senescent. Mature trees of *Populus tremula* (diameter of trunk = 20-40 cm) were occurred locally, but lack of target lichen species. *Padus avium* Mill grow in undergrowth and often appear to be a phorophyte for *Graphis scripta* due to smooth translucent upper part of the bark.

About one thousands of trees were examined and seven species of protected lichens included to the Red Data Book of the Altai Territory (Davydov 2016) were identified in *Tilia sibirica* forests in Salair area in Altai Territory (Fig. 1). The distribution of lichens across five phorophyte species is shown on the Table 1.

Lichen / Phorophyte	Number of trees	<i>Graphis scripta</i>	<i>Heterodermia speciosa</i>	<i>Lobaria pulmonaria</i>	<i>Nephroma bellum</i>	<i>Ramalina roesleri</i>	<i>Ramalina sinensis</i>	<i>Ramalina vogulica</i>
<i>Tilia sibirica</i>	626	167	22	4	1	234	15	8
<i>Abies sibirica</i>	165	0	0	0	0	1	0	0
<i>Sorbus sibirica</i>	53	2	0	0	0	0	0	0
<i>Populus tremula</i>	15	0	0	0	0	0	0	0
<i>Padus avium</i>	64	0	0	0	0	0	0	0

Table 1. Distribution of protected lichens on different phorophytes in *Tilia sibirica* dominated forests of the Salair area of the Altai Territory

Protected lichens were found on three phorophytes – *Tilia sibirica*, *Abies sibirica*, and *Sorbus sibirica*. *Tilia sibirica* dominated numerically as well as in the area of the bark. Most of the remaining trees are located in the second forest floor, in places unfavorable for lichens. Moreover, the average age of *Tilia sibirica* is more than remaining trees except probably *Populus tremula*. All species were found mostly on the *Tilia sibirica*. In addition, *Ramalina roesleri* was found at once on *Abies sibirica* and *Graphis scripta* – twice on *Sorbus sibirica*. The total projecting cover of protected

lichens across sites is shown on the Table 2.



Figure 1. Linden forest in Salair National Park.

Lichens / Site No.	Number of trees	<i>Graphis scripta</i>	<i>Heteroderm ia speciosa</i>	<i>Lobaria pulmonaria</i>	<i>Nephroma bellum</i>	<i>Ramalina roesleri</i>	<i>Ramalina sinensis</i>	<i>Ramalina vogulica</i>
1	34		15			363.75		45
2	31	0.25				15.7		
3	20	12				26		
4	11	22.5	5.5			23.75		
5	20	247.75				31.29		
6	44	19.25				29.35	5	
7	28	1106.7				63	3.25	
8	23	43.5	46.25	1403	200	24.5	5.75	1
9	21	41				21.25		
10	23	54.5		4		66	1	
11	17					26.5		
12	19	13.5				9.5		
13	32	244				12.5		
14	17	230	2			205		

15	18	47.5	4			32.5		4
16	20	595.5				7.5		
17	44		6.5			58		
18	23	5.5	35.5			39.5		
19	17	72.5	69.5	99		25	1	
20	17	115				70	5	
21	16	66.5				15.5	1	
22	17	309.5				124.5	1	
23	33	86.5				31.5	1	0.5
24	32	22.5				33.5		
25	14	57.5	60			39.5		

Table 2. Total projecting cover of protected lichens on sites in *Tilia sibirica* forests (dm²).

Graphis scripta is common in *Tilia sibirica* forests. Populations were found in 22 localities out of 25. Thalli were found on bark of two phorophytes: *Tilia sibirica* and *Sorbus sibirica* in the height range, mainly from 0.5 to 2 m from the soil level. The species lives on young and mature trees, erect or tilted, but only on smooth bark. The area of thalli on a single tree varies from 0.25 cm² to 204 cm² with the average value 18.3 cm². The population relative area in *Tilia sibirica* forests is 34.15 dm² / ha. The species is quite rare on Salair.

Heterodermia speciosa is a rare species, recorded in *Tilia sibirica* forests in nine localities out of 25. It grows at the same microhabitats as *Lobaria pulmonaria*, i.e. on mossed bark of *Tilia sibirica*. The area of thalli on a single tree varies from 11.5 cm² to 23 cm² with the average value 11.2 cm². The population relative area in *Tilia sibirica* forests is 34.15 dm² / ha. The population relative area in *Tilia sibirica* forests is 2.47 dm² / ha. The species is quite rare on Salair.

Lobaria pulmonaria was found only in three localities out of 25, and only on four *Tilia sibirica* trees (Fig. 2). *L. pulmonaria* grows on mossy trunks and in three cases out of four on tilted trees. The area of thalli on a tree is from 4 cm² to 800 cm². The population relative area in *Tilia sibirica* forests is 14.03 dm² / ha. On Salair, the species mainly inhabits in *Salix* forests, where it lives on *Salix* bark. The species is quite rare on Salair.



Figure 2. *Lobaria pulmonaria* in the trunk of *Tilia sibirica*.

Nephroma bellum was found only in single locality of *Tilia sibirica* forests, where it grew together with *Lobaria pulmonaria*. The total area of the thalli is 200 cm². *Nephroma bellum* is demanding to high humidity and sensitive to environmental changes (Zavarzin and Davydov 2000; Davydov 2016). The population relative area in *Tilia sibirica* forests is 2.00 dm² / ha. The species is extremely rare on Salair.

Ramalina roesleri (Schaer.) Hue is the most common protected species found on Salair. It was found in different abundance on the bark and branches of *Tilia sibirica*, much less often on *Abies sibirica*. It lives on young, mature and old trees, as well as dry trees of different diameters, from 6 to 45 cm, both erect and inclined trunks, especially abundant on dry branches of *Tilia sibirica*. It occurs both as individuals, with a total area of 1–10 cm² on a single tree and in large groups, with an area of up to 100–110 cm². The area of thalli on a single tree varies from 0.25 cm² to 109 cm² with the average value 5.1 cm². The population relative area in lime forests is 13.95 dm² / ha. The species is quite common on Salair.

Ramalina sinensis Jatta was found in 9 of the 25 localities, in seven of them only on one tree, in

one-on three trees and in one – on five trees, always in small abundance. It lives on young, mature and old trees, as well as dead wood. The area of thalli on a single tree varies from 0.25 cm² to 5 cm² with the average value 1.6 cm². The population relative area in *Tilia sibirica* forests is 0.24 dm² / ha. The species is quite rare on Salair.

Ramalina vogulica Vainio is a rare species, is recorded in *Tilia sibirica* forests in 4 localities out of 25, in three of them – on a single tree and in one – on five trees. The area of thalli on a single tree varies from 0.5 cm² to 14 cm² with the average value 6.3 cm². The population relative area in linden forests is 0.50 dm² / ha. The species is extremely rare on Salair.

Discussion

The similar research was recently carried out in *Picea obovata* and *Abies sibirica* dominated forests in Salair area (Davydov et al. 2020). The data on magnitude of population is shown compared to our data (Table 3). In total, eight species of protected lichens was identified, all but one of them occurred in *Tilia sibirica* forest. *Usnea longissima* Ach. is the boreal species recorded in Altai Territory in *Abies sibirica* forests (Davydov 2004), so the absence of this species in lime forest is not surprising. In contrast, only two species recorded on sample plots in *Picea obovata* forest and five species in *Abies sibirica* forests. *Lobaria pulmonaria* and *Nephroma bellum* are also occurred in *Abies sibirica* forests but outside the sample plots, which indicates the rarity of mentioned species. *Ramalina roesleri* and *R. sinensis* are distributed in all three types of forests with maximal magnitude in *Abies sibirica* forests and minimal in *Picea obovata* forests. In general, *Graphis scripta* and *Ramalina roesleri* are the most abundant protected species within the Salair area.

Lichen species / forest dominant	<i>Tilia sibirica</i>	<i>Picea obovata</i>	<i>Abies sibirica</i>
<i>Graphis scripta</i>	34.15	–	2.6
<i>Heterodermia speciosa</i>	2.44	–	–
<i>Lobaria pulmonaria</i>	15.06	–	–
<i>Nephroma bellum</i>	2	–	–
<i>Ramalina roesleri</i>	13.96	1.8	28.3
<i>Ramalina sinensis</i>	0.24	0.9	3.49
<i>Ramalina vogulica</i>	0.5	–	0.11
<i>Usnea longissima</i>	–	–	1.2

Table 3. Relative thallus area (dm²/ha) in populations of protected lichens in different forests in Salair area

Conclusion

Seven species of protected lichens were identified in *Tilia sibirica* forests in Salair area in Altai Territory. All species were found mostly on the *Tilia sibirica*. Linden forest has a high conservation value regarding lichens. *Graphis scripta* and *Ramalina roesleri* are common within the area, while *Heterodermia speciosa*, *Lobaria pulmonaria*, *Nephroma bellum*, *Ramalina sinensis*, and *R. vogulica* are rare. New quantitative data on cenopopulations of the studied lichen species in Salair region have been obtained.

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