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Current state of *Lobaria pulmonaria* in southernmost Sweden

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Sites of *Lobaria pulmonaria* reported from the nemoral zone of the Swedish provinces Skåne and Blekinge since 1990 were revisited. At each locality, the habitat ecology and lichen viability were investigated. A substantial decline was noted, particularly in Skåne, as *L. pulmonaria* was found at only 24 sites, 22 of which were forests and two were wooded meadows. The commonest habitats for *L. pulmonaria* were *Tilio-Acerion* forests and species-poor, oligotrophic beech forests, and the commonest substrates were trunks of *Acer platanoides* and *Fagus sylvatica*, followed by *Quercus robur*. The inhabited trees grew often in the upper part of steep slopes or rock faces, either on rocky or boulder-rich, meso- to oligotrophic soils. *Lobaria pulmonaria* showed a preference for locally cool climates. It had survived at sites offering a stable environment in terms of light, moisture and temperature, with minor influence of air pollution, agriculture and forestry practices.

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Introduction

Lobaria pulmonaria (L.) Hoffm. has a wide distribution range, comprising the Northern Hemisphere, East and South Africa (for detailed information see Litterski 1999). Today, it is rare for various reasons in many areas such as the central European lowland (e.g. Wirth et al. 2013, Fałtynowicz 1992), and the nemoral zone in Scandinavia that includes Denmark and southernmost Sweden (Degelius 1935, Hallingbäck & Olsson 1987, Jørgensen & Tønsberg 2007, Schiefelbein et al. 2016, 2017, Søchting & Christensen 1989, Virtuella herbariet, <http://www.emg.umu.se>).

In Sweden, *L. pulmonaria* is still more common in the north, but it disappeared from southwestern Skåne long before Artportalen. The botanical collections at the Biological Museum, Lund University host specimens from Dalby (1880s to the early 1900s) and from Hardeberga (1909), both sites in the vicinity of Lund. In southern Skåne, it was found in Näsbyholm in Gärdslov parish (1901), in the southeastern Skåne, at Stenshuvud (1934), and in central Skåne at Trolleholm in Torrlösa parish in the 1890s (Virtuella herbariet, <http://www.emg.umu.se>). Major reasons for its decline are due to forestry, agricultural practices and pollution (Andersson & Appelqvist 1987, Carlson & Nilsson 2009, Edman et al. 2008, Gauslaa 1995, Gustafsson et al. 1992, Gustafsson & Milberg 2008, Hallingbäck & Martinsson 1987, Hallingbäck & Olsson 1987, Jürriado & Liira 2009, 2010, Öckinger et al. 2005, Søchting & Christensen 1989).

During two field visits, *L. pulmonaria* was searched for in parts of the nemoral zone of Sweden, from Skåne to southern Öland by checking sites reported to Artportalen after 1990 (Artportalen 2016–2017, <https://www.artportalen.se>). The first visit in 2016 included most of Skåne, whereas the second visit in 2017 covered northeastern Skåne, southern Blekinge,

southwesternmost Småland and southern Öland. The decline of *L. pulmonaria* in southern and eastern parts of Skåne was substantial, since it was found at only seven sites, whereas a higher survival occurred at the sites visited 2017 (Schiefelbein et al. 2016, 2017). With the exception of one single transplanted specimen, it appears to be extinct from southern Öland (Schiefelbein et al. 2016, 2017). The species was also considered to be extinct from southwesternmost Småland at its last locality in Mortorp southwest of Kalmar (Schiefelbein et al. 2017), but a colleague recently reported small thalli remaining at this locality and will be evaluated in a separate publication.

In this study, the habitat, ecology, viability, abundance and recent distribution of *L. pulmonaria* were evaluated in detail.

Material and Methods

All sites reported to Artportalen (www.artportalen.se) for *L. pulmonaria* in Skåne, and southern Blekinge since 1990 were re-visited except for few difficult to reach remote sites. The inventory was carried out during 30 June–4 July 2016 and 11–15 May 2017. Notes were made on the presence or absence of the species, and for possible causes of disappearance (Schiefelbein et al. 2016, 2017). The species was searched for not only at the original locality, but also in the suitable surroundings. Fragments were collected to be included in an on-going population genetic study.

The following variables were recorded: (1) habitat type, (2) soil type, (3) relief, (4) light condition, (5) host tree species, (6) girth of host tree, (7) aspect of *L. pulmonaria* specimens on the tree, (8) inclination of the substrate, (9) height and vertical distribution of *L. pulmonaria* on the inhabited tree, (10) bryophyte and lichen cover on the inhabited tree, and (11) viability of the population on the host tree. (1) The habitats were classified into six classes: species-poor, oligotrophic beech forests; species-rich, eutrophic beech forests; species-poor, acidophilous oak forests; oak-hornbeam forests; *Tilio-Acerion* forests; wooded meadow. (2) The soils were characterized based on the known requirements of the herb vegetation and the presence/absence of boulders or rocks. Acidic, nutrient-poor soils; acidic, nutrient-poor soils rich in boulders or shallow over rocks; base-rich, moderately or nutrient-rich soils; base-rich, moderately or nutrient-rich soils rich in boulders or shallow over rocks were differentiated. (3) Four topographic categories were distinguished: slopes; ridges/crests; valley bottoms; ± flat plains. (4) The light regime for the host trees was visually estimated as open, sunny locations; partially shaded locations (forests with a more or less open canopy); shady places (forests with a closed canopy). (10) Bryophyte and lichen cover on the inhabited tree were estimated in a typical place on an area of 50×50 cm. (11) Four classes of viability of the population on the host tree have been distinguished: specimens of populations with poor viability were strongly damaged; there were no young thalli, populations were of very few small specimens; of moderate viability were populations with partly damaged specimens or lobes, respectively; healthy lobes were only few at the edge of thalli and younger thalli were almost absent; specimens of population of good viability bore isidia, phyllidia or soredia in abundance; most thalli look healthy, younger thalli are usually present; population with specimens bearing apothecia on the thalli were considered as of very good viability. The viability of the host tree was not evaluated unless it was dead.

For an evaluation of the climatic preferences and the cartographic representation of climatic conditions in the study area the Global Climate Data system was applied (<http://www.worldclim.org/>, Version 2, consulted 22 February 2018; Fick & Hijmans 2017). The following categories were used: annual mean temperature (Bio1) and annual precipitation (Bio12). The climatic data were determined at a spatial resolution of c. 1 km².

Study Area

The study area comprised most of the nemoral zone of southern Sweden, covering Skåne and southern Blekinge, but did not cover the west coast of Sweden. The landscape is flat or hilly, reaching a maximum elevation of 212 m above sea level. In Skåne, the southwestern part is characterized by open fields and deciduous forests, whereas a mixed, more forested landscape dominates northeastern and southern Blekinge. The potential natural vegetation of the study area is probably mainly oligo- (to mesotrophic) beech forests, eutrophic beech forests and oligotrophic acidophilous oak forests (Bohn & Neuhäusl 2000/2003). Eutrophic beech forests would naturally occur mainly in southwestern and eastern Skåne but have often been transformed into agricultural land. Because of the lower suitability for agriculture, the oligo- (to mesotrophic) beech and acidophilous oak forests are still more present. In addition to beech and acidophilous oak forests, oak-hornbeam and alder carrs and swamp forests would have naturally covered the study area (Bohn & Neuhäusl 2000/2003). The distribution of the different potential natural vegetation types can be seen in Fig. 7.

The climate is temperate and characterized by moderate temperatures (average annual range 6.2–8.9°C) (Fig. 5), and the average annual precipitation ranges from 480 to 1060 mm (Fick & Hijmans 2017) (Fig. 6).

Results

Twenty-two of the investigated sites and 40 host trees were in forests, and only two populations occurred on trees in wooded meadows. Seven sites and 18 host trees of *L. pulmonaria* were observed in *Tilio-Acerion* forests, 11 sites and 14 host trees in species-poor, oligo- to mesotrophic beech forests, 2 sites and 6 trees in species-rich, eutrophic beech forests, and only 2 sites and 2 trees in oak-hornbeam forests. Most of the inhabited trees grew on more or less steep slopes or rock faces: 13 were N-facing, 12 E-facing, 7 S-facing and 3 W-facing. Six trees were located on flat plains and one on a ridge. The soils were mostly shallow over rocks and/or rich in boulders, with no discrimination between base-rich soils (13 sites) and acid ones (11 sites).

Lobaria pulmonaria was found on six different tree species, the proportions of which are provided in Fig. 1. The host trees did not follow a particular distribution pattern; only *Fagus sylvatica* is concentrated in the Söderåsen National Park and the vicinity of Sölvesborg.

Lobaria pulmonaria occurred most frequently on trees with a circumference of 101–150 cm at breast height (Fig. 2), but a colonized *Carpinus betulus* tree had the smallest girth (35 cm), and two *Tilia cordata* trees had the largest girths (250 and 410 cm); girths circumferences less than 50 cm were only found on *Carpinus betulus* and *Acer platanoides*, and the smallest circumference for *Fagus sylvatica* was 75 cm and for *Quercus robur* 55 cm.

The height distribution of *L. pulmonaria* on the tree trunks was highly variable: on six trunks it occurred up to 1 m, 12 up to 2 m, 11 up to 3 m, 8 up to 5 m and 5 more than 5 m above the ground; the highest occurrence was at c. 10 m. The total vertical distribution on the trees ranged from a few centimeters up to 7 m, while the majority was between 50 and 100 cm (Fig. 3). *Lobaria pulmonaria* had no preference for a particular aspect of the trunk. It mainly colonized inclined and vertical parts of the trunk but was also found several times on horizontal and overhanging areas of the trunk. In Tåppet, Blekinge, it was confined to the lower side of the trunk of a *Fagus sylvatica* tree leaning at 30 degrees.

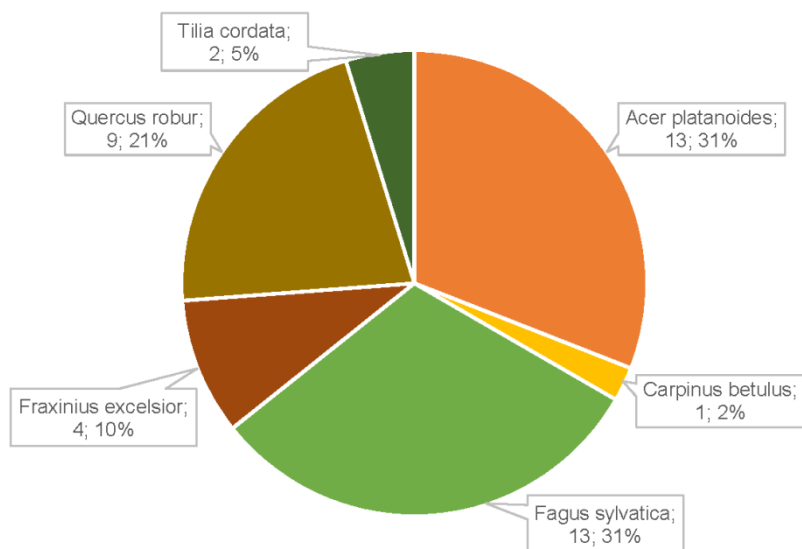


Figure 1. Number and proportion of tree species with *Lobaria pulmonaria* in the study area.

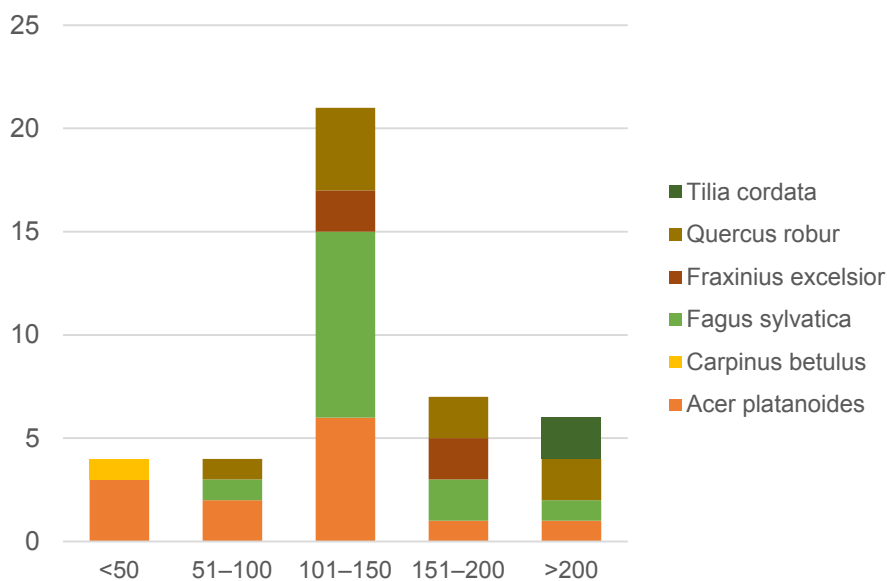


Figure 2. Frequency of the circumferences of the host trees with *Lobaria pulmonaria* (in cm) in the study area.

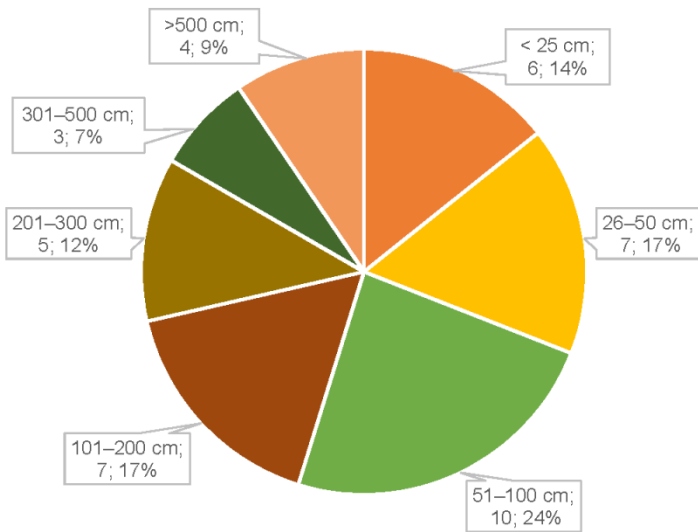


Figure 3. Number and proportion of vertical distribution classes of *Lobaria pulmonaria* on the trees.

Lobaria pulmonaria populations were healthy on about two thirds of the colonized trees, two of them even had apothecia. When the specimens were in good condition, bryophytes usually covered a large proportion of the investigated part of the trunk (Table 1). Exceptions were trees where the lichen cover was proportionally (much) larger than the moss cover, and a dead oak tree where *L. pulmonaria* grows on the remains of the bark (Table 1).

Lobaria pulmonaria appears to avoid warm areas in Skåne and Blekinge and occurred almost exclusively in regions where oligotrophic beech or acidophilous oak forests potentially form the natural vegetation (Fig. 7). The mean annual temperatures in the areas where *L. pulmonaria* grew are in the range 7.1–7.8°C (Fig. 5). The mean annual precipitation (Fig. 6) in the study area varied from c. 900 mm (892 mm in Söderåsen National Park) in the northern central Skåne to c. 600 mm (581 mm in Ringholmen near Ronneby) in eastern sites.

Table 1. Relation between the viability of *Lobaria pulmonaria* and moss cover on the trees.

Viability	Moss cover					Total
	1–10 %	11–25 %	26–50 %	51–75 %	76–100 %	
bad	1	0	2	1	1	5
moderate	0	1	4	1	4	10
good	5	6	8	2	4	25
very good	0	2	0	0	0	2
Total	6	9	14	4	9	42



Figure 4. *Lobaria pulmonaria* on *Quercus robur* in a species-poor, oligotrophic beech forest. The tree grows in the upper half of an E-exposed rock face, a typical site in the studied area.

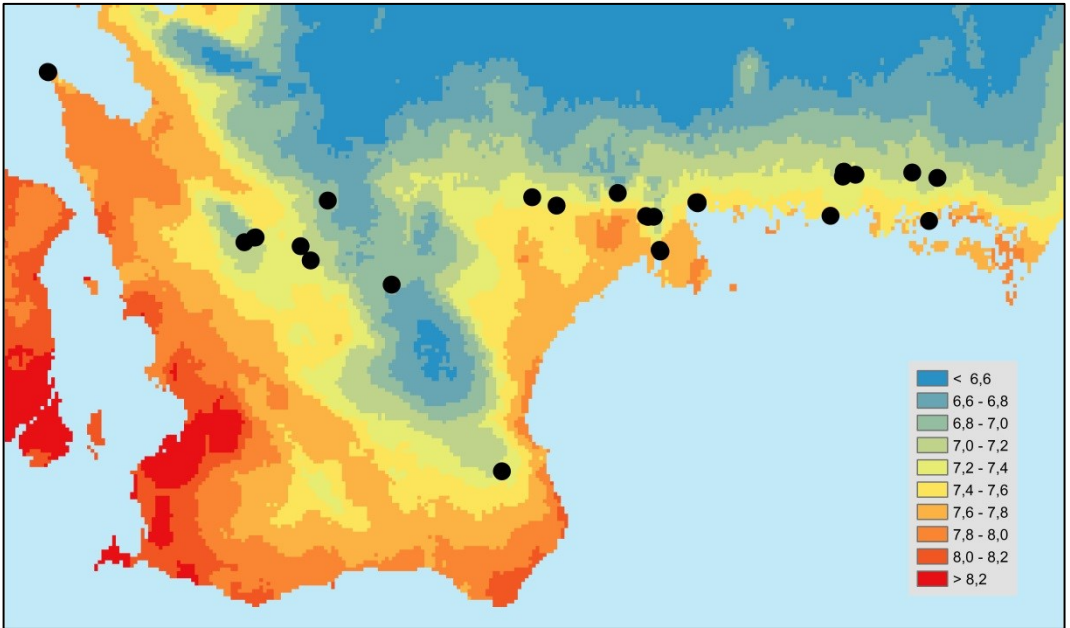


Figure 5. Annual mean temperature (in °C) according Fick & Hijmans (2017) and distribution of *Lobaria pulmonaria* in the study area.

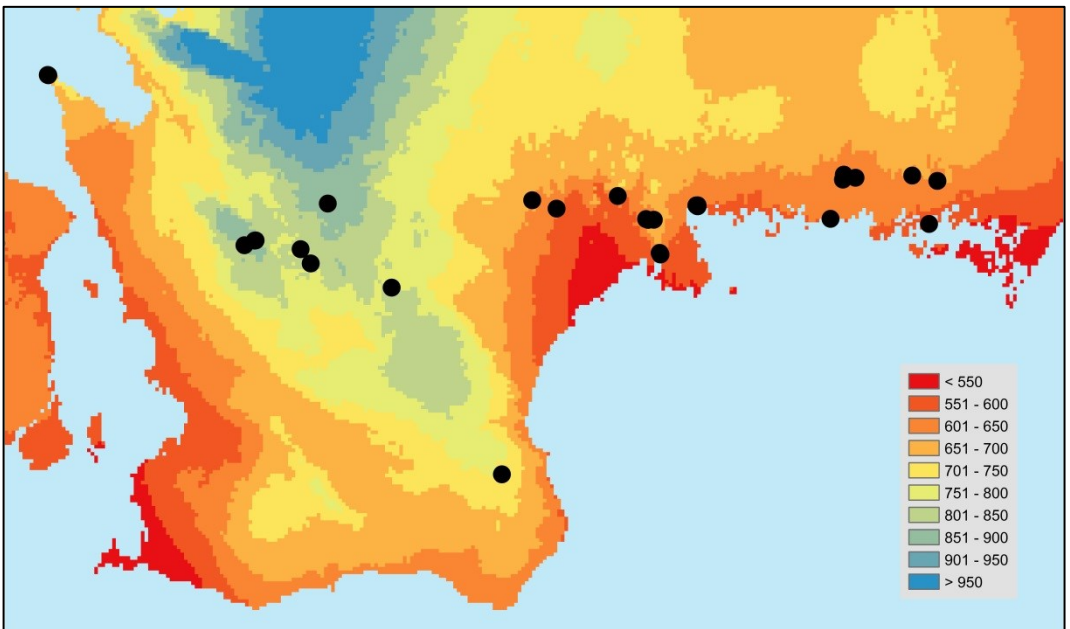


Figure 6. Annual precipitation (in mm) according Fick & Hijmans (2017) and distribution of *Lobaria pulmonaria* in the study area.

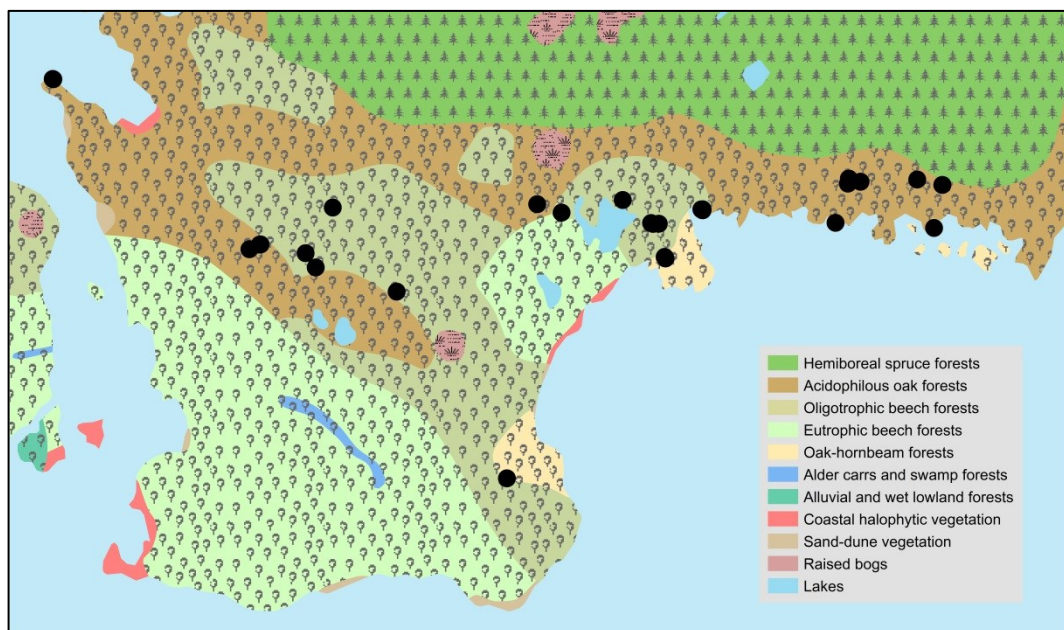


Figure 7. Potential natural vegetation according Bohn & Neuhäusl (2000/2003) and distribution of *Lobaria pulmonaria* in the study area.

Discussion

Lobaria pulmonaria was formerly widespread in the nemoral zone of southern Sweden, as the historical records from the GBIF database (<https://www.gbif.org>) and the Virtuella herbariet database (<http://www.emg.umu.se>) show. Today it is restricted to certain regions, habitats and locations where forest communities on rather nutrient-poor soils naturally dominate. In regions, where eutrophic beech forests or oak-hornbeam forests would form the natural vegetation cover, *L. pulmonaria* is now absent. These regions have more agriculture with less forest, and are more affected by, for example, airborne N-deposition, consistent with the observations of Skagerberg (2011) who noted the presence of *L. pulmonaria*, the size of the lichen thalli and the height of the lichen patches on the trunks were positively influenced by habitat size and adversely affected by habitat exposure. The effects of eutrophication on lichens, particularly the *Lobarion pulmonariae*, are well known (e.g. Hauck & Wirth 2010, Wolseley & James 2000). Therefore, eutrophication caused by industrialized agriculture is probably one reason for the extinction of *L. pulmonaria* in southwestern Skåne.

The recent distribution of *L. pulmonaria* in the study area shows an association with forests in areas with locally lower annual mean temperatures (Fig. 6). Low temperatures are associated with higher relative humidity and thus a higher frequency of nocturnal uptake of sufficient water vapour and/or dew (Gauslaa 2014). Rain, dew, and humid air are drivers of lichen morphology, function and spatial distribution (Gauslaa 2014). Such additional hydration sources may explain why annual precipitation has little influence on its local distribution. (Fig. 7).

Crucial to the occurrence of *L. pulmonaria* in regions with lower precipitation, as in the eastern part of the study area, is habitat quality. Currently, the most common habitats for *L. pulmonaria* in the study area are *Tilia-Acerion* forests and species-poor, oligotrophic beech forests. The investigated sites were often rocky places, where the trees mainly grow on steep slopes or rock faces. The soils were often acidic and poor in nutrients. These conditions guarantee that the trees grow slowly, and the light and humidity conditions change only slightly over a long period. Furthermore, these locations are less attractive for forestry and acidity substantially reduces the attack of gastropods (Gauslaa pers. comm.).

Lobaria pulmonaria does not appear to be tolerant to strong light in the study area, as it most often occurred in half-shaded and only exceptionally in sunny or dark-shaded places. In sunny locations, like wooded meadows, it occurred on sheltered sides of the trunk of very old trees. In exceptional cases, when *L. pulmonaria* grew fully exposed, it was found on trees standing close to water, on the Kullen peninsula near the seashore and at Lake Ivösjön. At many sites, it occurred on trees growing in the upper reaches of steep slopes or rock faces where more light penetrates the canopy. These occurrences are consistent with the results of various studies, such as Gauslaa & Solhaug (1999) who showed by laboratory experiments that a rapid raise of solar radiation is destructive for the lichen. Pannewitz et al. (2003) concluded that *L. pulmonaria* can occur in both shaded and open habitats, but prefers niches with low irradiance. Excess light can cause strong photo-inhibition in hydrated lichens, particularly in forest lichens and shade-adapted thalli (Gauslaa & Solhaug 1996), but insufficient light strongly limits its growth (Gauslaa et al., 2006; 2007). However, the growth is higher in old forests with gaps in the canopy offering some irradiance (Gauslaa 2013).

Almost two thirds of the investigated sites are, according our definition, in good condition and richly covered by bryophytes, which are typical for the *Lobarion pulmonariae* Ochs. community (Barkman 1958, Wirth 1968), but this should not hide the fact that even these locations are generally impoverished in lichen diversity as species of the genera *Heterodermia*, *Pannaria* and *Sticta*, which are also typical for this community, are absent.

In conclusion, *L. pulmonaria* has survived in the study area at sites offering a stable environment in terms of light, moisture and temperature, which has been little influenced by air pollution, agriculture and forestry practices.

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