

Threatened forest lichen *Lobaria pulmonaria* – its past, present and future in Estonia

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Abstract. *Lobaria pulmonaria* is a conspicuous and widely known epiphytic lichen species which mainly occurs on mature hardwood trees in old forests. The distribution of *L. pulmonaria* has become highly fragmented, showing a decline across Europe. *Lobaria pulmonaria* is unevenly distributed among ca. 600 localities in Estonia. Most localities are in north-eastern and south-western Estonia (50% and 21% of records respectively). 86% of *L. pulmonaria* localities are in nature reserves, national parks or woodland key habitats (WKH). In 81% of historical localities known until 1992, *L. pulmonaria* could be considered extinct. 6% of *L. pulmonaria* localities have become destroyed in the period from 1993 to 2010 due to clear cutting; in 19% of localities the species could be considered endangered, as its neighbourhood is affected by forest management activities. 40% of destroyed localities are located in forests designated as WKHs in north-eastern Estonia, and most of the endangered populations are also within WKHs. In forest management and conservation planning, WKHs should be preserved with surrounding buffer areas in order to avoid abrupt changes in environmental condition and natural disturbance regimes. There is also a necessity to develop specific management methods to recover reforested wooded meadows, to ensure that species of semi-open habitats are retained, e.g. by reducing the density of spruce.

Key words: endangered species, forest land changes, forest management, habitat destruction, wooded meadows.

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Introduction

Lobaria pulmonaria (L.) Hoffm. is a conspicuous and widely known epiphytic lichen species found in boreal, temperate, mountainous and oceanic areas of the world (Yoshimura, 1998). *Lobaria pulmonaria* is a characteristic species of the epiphytic alliance *Lobarion pulmonariae* Ochns., which is considered to be a climax lichen community on mature hardwood trees in old forests across Europe. It has been widely used as an indicator species of undisturbed forest ecosystems and forest areas of long ecological continuity (Rose, 1976; Andersson & Appelqvist, 1987; Andersson *et al.*, 2003; Liira & Sepp, 2009). Furthermore, as *L. pulmonaria* associates with many other rare or endangered lichen species (Campbell & Fredeen, 2004; Pykälä, 2004; Nascimbene *et al.*, 2010) and wood beetles (Nilsson *et al.*, 1995) of old growth forests, it has been used as a flagship or umbrella species for nature conservation (Scheidegger & Werth, 2009).

Destructive forest management is the main threat to *L. pulmonaria* in Europe.

The disruption of the historical continuity of forest stands, the replacement of natural hardwood forests by planted coniferous or deciduous softwood tree species and the short rotation period of stands have caused a decline in the abundance of *L. pulmonaria* and other associated species (James *et al.*, 1977; Rose, 1988, 1992; Wolseley & James, 2000). In addition to forest management, *L. pulmonaria* and other cyanolichens are sensitive to atmospheric pollutants (SO₂, O₃) and acid rain (Gauslaa, 1995; Goward & Arsenaault, 2000; Richardson & Cameron, 2004).

In contrast to its overall European status, *L. pulmonaria* is still frequent in Fennoscandia and in the Baltic region. Here the lichen has mainly been recorded in small and fragmented old forest patches in managed forests (Auziņš & Ek, 2001; Gu *et al.*, 2001; Andersson *et al.*, 2003; Pykälä, 2004; Jüriado & Liira, 2009), and it prefers large-diameter host trees (Riiali *et al.*, 2001; Öckinger *et al.*, 2005; Gu *et al.*, 2001; Mikhailova *et al.*, 2005; Edman *et al.*, 2008; Belinchon *et al.*, 2009). In highly humid conditions, *L. pulmonaria* also occurs on younger trees and on rocks (Hakulinen, 1964; James *et al.*, 1977; Carlsson & Nilsson, 2009). *Lobaria pulmonaria* colonizes the bark of many tree species. For example, it has been found on 28 tree species in Russia (Istomina, 1996), and on 17 tree species in both Finland (Hakulinen, 1964) and Estonia (Jüriado & Liira, 2009). Deciduous trees with well-buffered bark and a pH of 5–6, such as *Fraxinus excelsior* and *Populus tremula* (James *et al.*, 1977; Jüriado & Liira, 2009) or *Quercus robur* bark with pH > 5 (Gauslaa, 1985; Torim, 2009) are the most preferred host trees for *L. pulmonaria*.

The aim of this study is to review the distribution of *L. pulmonaria* in Estonia since the end of the 19th century, and to analyse changes in its distribution during the periods from 1897 to 1992 and from 1993 to 2010.

Material and Methods

Study area

Estonia has a flat topography. Average air temperature in Estonia is approximately 17 °C in July and -6.5 °C in January (Jaagus, 1999). Precipitation is higher on the uplands of the northern and south-eastern regions (650–700 mm yr⁻¹) than in coastal areas, including the islands (500–550 mm yr⁻¹) (Jõgi & Tarand, 1995).

About half of Estonia's mainland territory is covered by forest (Kohava, 2001). Estonian forests belong to the hemi-boreal subzone of the boreal forest zone (Ahti *et al.*, 1968). According to the Estonian Statistical Forest Inventory, only 2–4% of forests are in a near-natural status (*sensu* Kohv & Liira, 2005), about 79% are intensively used for commercial purposes and 28% of forests are affected by edge-effect (Adermann, 2009). In Estonia, selective cutting of sub-mature stands before clear-cutting is the main management activity in commercial forests. Reforestation is based on natural recovery or planting of spruce and pine. Therefore many stands are secondary by their origin, mostly intensively managed and monocultured (Sepp *et al.*, 1999; Adermann, 2009). Many present-day hardwood rich forests have developed from wooded meadows, which were widespread traditional semi-natural ecosystems until the middle of the 20th century (Kukk & Kull, 1997). Wooded meadows used to have scattered shrubs and solitary trees, including *Quercus robur* of high age. Traditional management has now ceased in most wooded meadows, and therefore these areas have become overgrown by deciduous or mixed forests.

Data sources

We used different data sources to give an overview of the distribution of *L. pulmonaria* in Estonia. In a previous review (Jüriado & Liira, 2009), we extracted information from the personal notes and herbarium specimens deposited in the lichenological herbarium at the Natural History Museum of the University of Tartu (TU), the database of the survey “Estonian Forest Conservation Area Network” (Viilma *et al.*, 2001), and the database of the Woodland Key Habitat Inventory (Andersson *et al.*, 2003). We updated the previous dataset with the database of the Ministry of the Environment (EELIS), records of some other forest study projects (Nõmm, 2005; Liira & Sepp, 2009; Torim, 2009) and unpublished personal data (A. Animägi, K. Jürgens, E. Leppik, I. Leppik, P. Lõhmus, L. Marmor, M. Nõmm, R. Nellis, A. Suija, U. Timm, A. Täpsi and T. Tüرنpu). By combining data sets and pooling spatially overlapping records, we obtained a database of 621 records of *L. pulmonaria* in Estonia for the period 1993 – 2010 (localities registered by means of GPS), and 75 historical records and observations from the period of preceding intensive inventories (the period 1897–1992), which frequently yielded imprecise location information.

For the assessment of the current status of *L. pulmonaria* localities, we used orthophotos of the Web Map Server of the Estonian Land Board (<http://xgis.maaamet.ee>). We classified the status of localities of *L. pulmonaria* populations into three categories: 1) “extinct” – clear-cutting has taken place in the locality (destroyed locality), 2) “endangered” – the locality of *L. pulmonaria* is neighboured by a clear-cut forest edge (less than 30 m) on at least two sides of the forest compartment, which increase the probability of habitat destruction in future, 3) “safe” – forest management activities have not taken place in or near the forest compartment.

We performed the analysis of the distribution of *L. pulmonaria* in various counties and nature protection categories using the map layers of protected forest areas (nature reserves, national parks) and woodland key habitats (from the Estonian Nature Information System, EELIS). For the updated distribution map of *L. pulmonaria* in Estonia, we separately illustrate the destroyed localities with historical localities of *L. pulmonaria* and recently recorded data from the period 1993 – 2010.

Results

Lobaria pulmonaria is unevenly distributed in Estonia. The densest cluster of localities is in north-eastern Estonia, where 50% of the Estonian *L. pulmonaria* records are registered (i.e. 205 records, 33% of the total are from Lääne-Viru County and 108 records, 17%, originate from Ida-Viru County) (Fig. 1, Table 1). The second region in Estonia with numerous records of *L. pulmonaria* is located in the south-western part of Estonia, with 21% of records (127 records in Pärnu County). The other 12 counties of Estonia hold from 0.5% to 6% of the national records.

The overlaying of map layers showed that 86% of *L. pulmonaria* records in Estonia are located in nature reserves, national parks or in woodland key habitats (WKH) (532 records), whereas 38% of records are in nature reserves or national parks, and 67% of records are in WKHs located inside or outside nature reserves or national parks.

In 81% of historical localities of Estonia (61 localities from the period of 1897 to 1992) with no recent records, *L. pulmonaria* can be considered extinct. Many of those old records are from the territory of cities (Tallinn, Tartu), or from parks in central and southern Estonia (Fig. 2).

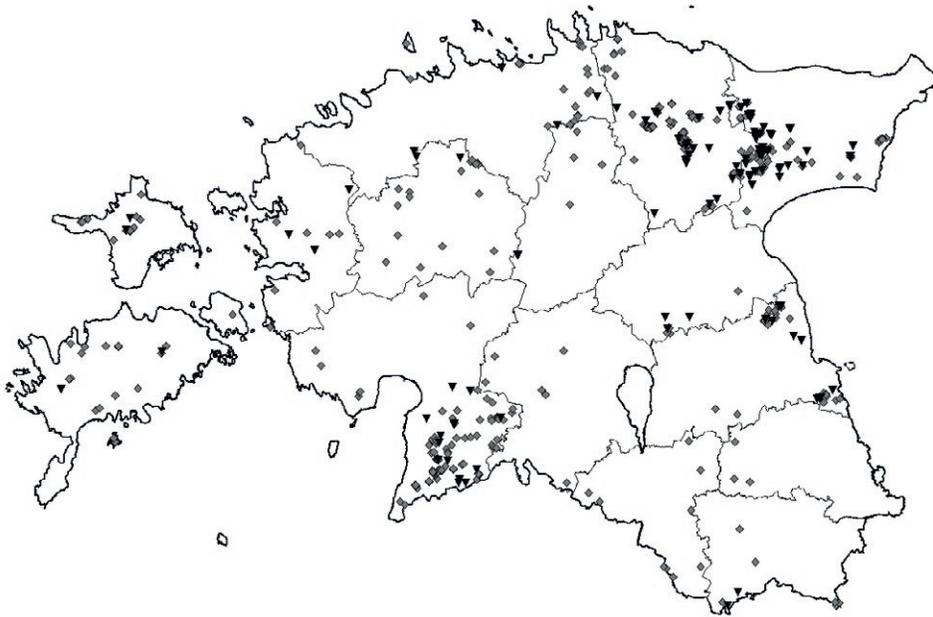


Figure 1. Distribution map of *Lobaria pulmonaria* in Estonia in the period 1993–2010. Quadrates indicate “safe” localities of *L. pulmonaria*, and triangles represent “endangered” localities.

Joonis 1. Hariliku kopsusambliku (*Lobaria pulmonaria*) leiukohad Eestis ajavahemikul 1993 kuni 2010. Rombid tähistavad “stabiilseid” hariliku kopsusambliku leiukohti ja kolmnurgad tähistavad “ohustatud” leiukohti.



Figure 2. Distribution map of historical records of *Lobaria pulmonaria* in Estonia (circles) in the period 1897–1992. Filled symbols denote localities destroyed during the years 1993–2010.

Joonis 2. Hariliku kopsusambliku (*Lobaria pulmonaria*) ajaloolised leiukohad Eestis ajavahemikul 1897 kuni 1992 (tühjad ringid). Täidetud ringid tähistavad hävinud hariliku kopsusambliku leiukohti ajavahemikul 1993 kuni 2010.

During the years 1993 to 2010, 6% (35) of *L. pulmonaria* localities have been destroyed by clear cutting (Fig. 2, Table 1), and in 19% (115) of the localities the species could be defined as endangered, as the locality or its near vicinity are affected by forest management activities (Fig. 1, Table 1). In 75% of *L. pulmonaria* localities (471), no significant changes have taken place during the years 1993 to 2010 (Table 1). One must note that map data for some regions have not been fully updated in the Land Board orthophoto collection, which means that the number of existing localities may be somewhat overestimated.

Seventy-seven percent of extinct populations (27) are in north-eastern Estonia (from Ida-Viru and Lääne-Viru Counties), and 12% (4) of destroyed localities are in south-western Estonia (Pärnu County) (“extinct” in Table 1). Similarly, the proportion of endangered localities is highest in north-eastern Estonia (from Ida-Viru and Lääne-Viru Counties; 59%; 68 localities) and south-western Estonia (Pärnu County; 14%; 16 localities) (Table 1).

Fifty-five percent of extinct populations of *L. pulmonaria* (19) are from commercial forests (outside protected areas and areas not designated as WKHs) (Table 1). 40% of destroyed localities (14) are WKHs, whereas only two localities have been destroyed in protected areas. 18% (21) of endangered localities are outside protected areas and/or forests designated as WKHs, and 82% (94) of endangered localities are in WKHs or in protected areas (Table 1).

Table 1. Distribution of localities of *Lobaria pulmonaria* in 15 counties of Estonia in protected areas (nature reserves, national parks) or woodland key habitats (WKH) (“P & WKH”) and non-protected areas (“N-p”) in the period 1993–2010. The status of localities of *L. pulmonaria* is presented in three categories: “safe”, “endangered” and “extinct”.

Tabel 1. Hariliku kopsusambliku (*Lobaria pulmonaria*) leiukohad kaitsealadel (looduskaitsealad ja rahvusparkid) ja vääriselupaikades (ühendatult “K & VEP”) ning mittekaitstavatel aladel (“M”) 15 Eesti maakonnas põhinedes ajavahemiku 1993 kuni 2010 andmetel. Hariliku kopsusambliku leiukohad on jaotatud kolme kategooriasse: “stabiilne”, “ohustatud” ja “hävinud”.

| County <i>Maakond</i> | Safe / <i>Stabiilne</i> | | | Endangered / <i>Ohustatud</i> | | | Extinct / <i>Hävinud</i> | | | Grand total <i>Üldsumma</i> |
|--------------------------------|-------------------------------|-----------------|---------------------------------------|-------------------------------|-----------------|---------------------------------------|-------------------------------|-----------------|---------------------------------------|--------------------------------|
| | P & WKH <i>K & VEP</i> | N-p <i>M</i> | Total <i>Kogu-</i> <i>summa</i> | P & WKH <i>K & VEP</i> | N-p <i>M</i> | Total <i>Kogu-</i> <i>summa</i> | P & WKH <i>K & VEP</i> | N-p <i>M</i> | Total <i>Kogu-</i> <i>summa</i> | |
| Harju | 20 | 2 | 22 | 4 | | 4 | | | | 26 |
| Järva | 6 | | 6 | 1 | 1 | 2 | | | | 8 |
| Rapla | 16 | 3 | 19 | 2 | | 2 | | | | 21 |
| Ida-Viru | 48 | 6 | 54 | 32 | 10 | 42 | 6 | 6 | 12 | 108 |
| Lääne-Viru | 137 | 27 | 164 | 24 | 2 | 26 | 9 | 6 | 15 | 205 |
| Lääne | 5 | 1 | 6 | 3 | | 3 | | | | 9 |
| Hiiu | 12 | | 12 | 1 | 1 | 2 | | | | 14 |
| Saare | 16 | 4 | 20 | 2 | | 2 | | 1 | 1 | 23 |
| Pärnu | 104 | 3 | 107 | 12 | 4 | 16 | | 4 | 4 | 127 |
| Valga | 9 | 1 | 10 | | | | | 1 | 1 | 11 |
| Viljandi | 7 | | 7 | | | | | | | 7 |
| Jõgeva | 6 | | 6 | 3 | 1 | 4 | | | | 10 |
| Tartu | 24 | 2 | 26 | 8 | 2 | 10 | 1 | 1 | 2 | 38 |
| Põlva | 4 | | 4 | | | | | | | 4 |
| Võru | 8 | | 8 | 2 | | 2 | | | | 10 |
| Grand total <i>Üldsumma</i> | 422 | 49 | 471 | 94 | 21 | 115 | 16 | 19 | 35 | 621 |

Discussion

In spite of the many localities of *Lobaria pulmonaria* in Fennoscandia and the Baltic region (Andersson *et al.*, 2003; Pykälä, 2004; Jüriado & Liira, 2009), the species is still threatened on the European level. In Estonia, *L. pulmonaria* is threatened because it prefers over-mature and old stands, and particularly stands of rare types (e.g. eutrophic boreo-nemoral forests) or stands that are under strong economic pressure (e.g. oligo-mesotrophic boreal forests) (Jüriado & Liira, 2009). The threat arises from the short rotation period of stands (the clear-cut cycle) (Snäll *et al.*, 2005), which changes stand composition from host trees preferred by *L. pulmonaria* to more economically profitable ones (Jüriado & Liira, 2009). The extensive loss and fragmentation of old-growth forests in the managed forest landscape of Europe has resulted in a more scattered habitat mosaic and lower overall incidence of *L. pulmonaria* (Gu *et al.*, 2001). The extended rotation cycle of stands could promote the persistence of this species in a managed forest landscape (Edman *et al.*, 2008). At the stand level, however, selective cutting has a strong negative impact on the abundance, frequency and fertility of *L. pulmonaria* (Edman *et al.*, 2008), and also affects the spatial distribution and dynamics of *L. pulmonaria* (Gu *et al.*, 2001).

In Estonia, the largest populations of *L. pulmonaria* occur in two regions with the largest proportion of forest cover and historical continuity (Ida- and Lääne-Viru Counties in north-eastern Estonia and Pärnu County in south-western Estonia) (Figure 1). At the same time, those populations, particularly in north-eastern Estonia, have probably suffered most seriously due to the intensive use and fragmentation of forested land. In other areas of Estonia, sporadic locations of *L. pulmonaria* are distributed all over the mainland and larger islands, but still mostly in large patches of forest and mainly in protected areas or those designated as woodland key habitats. Based on the historical records, however, the species has become extinct in many localities near larger cities such as Tallinn and Tartu and in agricultural areas of central and southern Estonia. In these areas, an additional threat is locally-induced air pollution from urbanized and agricultural areas.

Roughly 3/4 of *L. pulmonaria* records in Estonia were found in small patches of mature and old-growth forest designated as woodland key habitats (WKH) within commercial forest landscapes. Nevertheless, a majority of woodland key habitats, particularly those situated on private land, are not covered by clearly-defined protection regulations or restrictions, as illustrated by the localization of 40% of destroyed localities of *L. pulmonaria* in WKHs. The conservation of key habitats as hotspots of biodiversity in a managed forest landscape is essential for old forests lichens (Berg *et al.*, 2002; Peterson & McCune, 2003), and their preservation in an intact state is vital. Additionally, as nearly one fifth of *L. pulmonaria* populations are endangered due to clear-cut forest edges, this means that the preservation of existing WKHs should be guaranteed, and their status should be protected by leaving forest buffer areas around them.

On the other hand, small remnant lichen populations in managed forest landscape may reflect the delayed response between habitat fragmentation and the extinction of the local population (Hanski, 1998; Gu *et al.*, 2001, Öckinger & Nilsson, 2010), since small populations are presumably vulnerable to disturbances (Scheidegger *et al.*, 1998). For example, 51% of the macrolichen populations (including *L. pulmonaria*) in Finnish key habitats found in the years 1989–1995 had disappeared by 2000 or 2001, mainly due to forestry activities (Pykälä, 2004). It is suggested that even if the remain-

ing old-growth sites are left uncut, the populations of *L. pulmonaria* likely decline, and the species is subjected to an extinction debt, driven by decreased amount and connectivity of suitable habitat over the last 150 years (Öckinger & Nilsson, 2010).

Although records of *L. pulmonaria* in wooded meadows represent only 10% of all Estonian records (Jüriado & Liira, 2009), some areas (Lasila, Haavakannu and Suurekivi Nature Reserves in Lääne-Viru County) of partially overgrown wooded meadows support a luxuriant populations of *L. pulmonaria* (Andersson *et al.*, 2003; Torim, 2009). *Lobaria pulmonaria* often grows in a large variety of semi-natural biotopes with scattered old trees, for instance, such as old parklands, pasture-woodlands and wooded meadows (e.g. Hallingbäck & Martinsson, 1987; Rose, 1992; Wolseley & James, 2000; Kalwij *et al.*, 2005; Carlsson & Nilsson, 2009; Jüriado & Liira, 2009). In semi-natural biotopes, optimized and adequate management of the habitat is crucial for the maintenance of endangered species, as both the cessation of traditional land use and too intensive management activities may threaten sensitive lichen species (Rose, 1992; 2001). Small-scale disturbances, e.g. the selective cutting of forest or woodland, need not be harmful to individual specimens of *L. pulmonaria* if the host trees and the potential host trees remain intact. Moreover, the increased amount of light may favour the lichen in the habitat (Gauslaa *et al.*, 2006; Coxson & Stevenson, 2007). Therefore we suggest that the restoration of overgrown wooded meadows in which *L. pulmonaria* is present should be done with special care, because abrupt changes in the light and moisture regime of the habitat likely affect the populations of *L. pulmonaria*. Even current habitat conditions should be improved, implying moderate management of the habitat like cutting of some trees to prevent closure of the canopy. In thinning, the conifers should be cut first, and the potential host trees of *L. pulmonaria* should be preserved. Potential host trees of *L. pulmonaria* should be preserved in the vicinity of ancient trees to increase the ability of the lichen to colonize the new habitat.

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Harilik kopsusamblik (*Lobaria pulmonaria*) – ohustatud metsasamblik Eestis minevikus, tänapäeval ja tulevikus

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Kokkuvõte

Harilik kopsusamblik (*Lobaria pulmonaria*) on iseloomulik liik Euroopa vanade laialehiste metsade samblikukooslustele, seetõttu on teda laialdaselt kasutatud looduskaitseväärusega metsade indikaatorliigina. Harilik kopsusamblik on Euroopas ohustatud ja mitmes regioonis isegi hävinud, seda eelkõige intensiivse metsamajanduse ja õhusaaste tõttu. Siiski on harilik kopsusamblik veel üsna sage näiteks Põhja-Euroopas ja Baltimaades. Seda samblikuliiki on siinkandis leitud eelkõige väikestes ja fragmenteeritud vanametsalaikudes, kus ta kasvab peamiselt suurediametrilistel puudel. Puudest eelistab ta hea puhverduisvõimega lehtpuude koort, mille pH on vahemikus 5–6, nagu näiteks harilikul saarel (*Fraxinus excelsior*) ja harilikul haaval (*Populus tremula*).

Et saada ülevaadet hariliku kopsusambliku levikudünaamikast Eestis 19. sajandi lõpust kuni tänapäevani, kasutasime erinevatesse andmebaasidesse koondatud levikuandmeid ja analüüsisime puistute seisundit kasutades erinevaid Maa-ameti kaardikihte. Korduvvaatluste eemaldamisel koosnes meie andmestik 75 ajaloolisest hariliku kopsusambliku leiukohast ajavahemikus 1897 kuni 1992 (intensiivsete metsainventeerimiste eelse perioodi kirjed on sageli ebatäpsete leiuandmetega) ja 621 kirjest, mis on üles märgitud aastatel 1993 kuni 2010 (leiukohad registreeritud GPS-iga metsaeraldise täpsusega).

Harilik kopsusamblik on Eestis ebaühtlaselt levinud, kasvades eelkõige metsades, kuid ka poollooduslikes kooslustes nagu puisniidud ja vanad pargid. Tänapäeval on hariliku kopsusambliku leiukohtade tihedus suurim Kirde-Eestis (50%; Ida- ja Lääne-Virumaa) ja Edela-Eestis (21%; Pärnumaa). Ülejäänud 12-s Eesti maakonnas varieerub leidude arv üldkogumist 0,5–6%. Leidudest 86% on teada looduskaitsealadelt, rahvusparkidest või vääriselupaikadest. 81% ajaloolises leiukohas (periood 1897–1992) on harilik kopsusamblik ilmselt hävinud, kuna seal puuduvad uuemad leiud. Liik on hävinud näiteks Tallinna ja Tartu linnast ja nende lähiümbrusest ning Kesk- ja Lõuna-Eesti parkidest, mis on ümbritsetud põllumajandusmaastikuga. Aastatel 1993 kuni 2010 on harilik kopsusamblik puistu lageraiete tõttu hävinud 6% leiukohtades. 19% kopsusambliku leiukohtadest on ohustatud, kuna metsaosas, kus samblik kasvab, piirneb vähemalt kahest küljest lageraielankidega. Hävinud leiukohtadest 40% ja enamus ohustatutest on Ida- ja Lääne-Virumaa metsade vääriselupaigad.

Metsade majandamise planeerimisel tuleb rõhku panna vääriselupaikade kaitsele ning nende ümber peaks planeerima puhverala, et tagada sobivad keskkonnamitingimused metsades kasvavatele vanametsasamblikele. Vanade kinnikasvanud puisniitude hooldamisel ja taastamisel tuleb kasutada majandusvõtteid, mis säilitaksid poolavatud kooslustele iseloomulikud kasvukohatingimused ja kasvupinnad. Eelkõige tuleks vähendada kuuskede järelkasvu ja tihedust.

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