Proc. Estonian Acad. Sci. Biol., 1996, **45**, 3/4, 181–191
https://doi.org/10.3176/biol.1996.3/4.07

AIR POLLUTION DEPOSITION IMPACT ON THE STRUCTURE OF BRYOPHYTE COVER IN SCOTS PINE FORESTS IN ESTONIA

Raimolt VILDE and Jüri MARTIN

Rahvusvaheline Keskkonnabioloogia Keskus (International Centre for Environmental Biology), P.O. Box 676, EE-0026 Tallinn, Eesti (Estonia)

Received 16 October 1996, revised version received 12 November 1996, accepted 18 November 1996

Abstract. The distribution and structure of moss synusiae in Scots pine forests (*Vaccinium* site type pine stands) along the environmental pollution gradient from NE (more polluted) to SW of Estonia was studied. The synusiae can be divided into two groups: (1) Synusiae whose distribution depends on the level of pollution. This group can be subdivided into 1a, the frequency is increasing on plots with higher pH values of the O horizon and 1b, the frequency is increasing on plots with lower pH values (typical of this type of forests); (2) Synusiae whose distribution is not directly affected by air pollution, the effect of phytocoenological, soil, and climatic factors being more important.

The structure of the bryophyte cover depends on the level of air pollution stress. In Estonia the general tendency of the thickness of bryophyte cover is to increase from NE to SW in all the synusiae. The thickness of both living and dead parts of bryophytes is substantially lower in the polluted NE part of the air pollution deposition gradient. The thickness of the soil O horizon is notably lower in NE than in SW.

The biomass of bryophytes by synusiae shows small differences along the air pollution deposition gradient. It has a tendency to decrease towards the polluted NE only in a few synusiae.

Key words: air pollution deposition gradient, bryophyte synusiae, structure of bryophyte cover.

INTRODUCTION

In early papers dealing with the response of bryophytes and their communities to air pollution impact mostly the presence or absence of species was observed as a response indicator (Barkman, 1958, 1968; Barkman et al., 1969; LeBlanc & De Sloover, 1970). Later it was found that most of the bryophytes are relatively tolerant to high concentrations of toxic substances such as sulphur compounds and heavy metals (LeBlanc & De Sloover, 1975; Rao et al., 1977; Manning & Feder, 1980; Tekko, 1991). However, using different community characteristics changes in the community structure can be found even in communities under low environmental stress. In recent publications, several other characteristics, such as coverage, frequency, thickness, density, fertility, vitality, etc., are often used in addition to the floristic composition of bryophyte communities (Отнюкова, 1985; Karofeld, 1994). Even specific anthropogenic bryophyte synusiae were found under the conditions of high industrial impact (Андреева, 1989; Andrejeva, 1990).

MATERIAL AND METHODS

To study the human impact (extensive pollution and physical disturbances, such as trampling, forest cutting, changes in forest structure, etc.) on bryophytes in forest communities, the changes in the structure of the bryophyte layer by synusia were analysed. Along the 250 km transect reflecting an air pollution deposition gradient in Estonia, six permanent study plots from NE to SW were observed. The vegetation communities chosen were as similar as possible (*Pinus–Vaccinium vitis-idaea–Pleurozium schreberi* ass., Laasimer, 1965).

Study site conditions. Some characteristics of the air pollution deposition gradient are given in Table 1. A more detailed description and the location scheme of this gradient is given by Martin and coauthors (1994, 1996) and in publications on the air pollution situation in Estonia (Kallaste et al., 1992; Eesti paiksetest ..., 1995).

Table 1

Some characteristics of the air pollution gradient in Estonia (data of meteorological stations)

Variables	Meteorological station			
	Jõhvi	Tiirikoja	Tooma	Sõrve
SO_4 deposition, mg/m^2	12 062	6107	4782	3796
pH of precipitation	6.65	5.77	5.70	5.39
NO_3^- deposition, mg/l	1.07	0.67	0.44	0.55

The following field plots with bryophytes cover were selected for forest study: 1. Narva-Jõesuu (NAR), 2. Kurtna (KUR), 3. Triigi (TRI), 4. Rannapungerja (RNP), 5. Tipu (TIP), and 6. Häädemeeste (HDM).

The climatic variables used in this paper demonstrate a rather uniform distribution over the whole study area. These data were taken from meteorological reports of the closest meteorological stations to the study plots (Table 2).

Table 2

Mean temperature and amount of precipitation in 1993 (data of meteorological stations)

Variables	Meteorological station					
	Narva	Jõhvi	Väike-Maarja	Tiirik-oja	Virtsu	Pärnu
Mean temperature, °C	4.53	4.38	4.28	4.55	4.97	5.83
Mean sum of precipitation, mm	597	694	692	597	807	748

Some variables characterizing the habitat conditions of the bryophytes on study plots along the transect are given in Table 3. As Table 3 shows there exists a strong gradient in the soil pH values, but the biotic factors (tree and herb layer characteristics) are relatively uniform for all study plots.

Table 3

Variables characterizing the bryophytes habitat conditions on study plots

Variables	Site					
	NAR*	KUR	TRI	RNP	TIP	HDM
Soil O horizon pH	5.91	5.16	3.36	2.99	3.11	3.02
Vascular plants coverage, %	25.8	16.8	20.9	28.1	23.2	22.5
Number of trees per hectare	540	1045	1080	795	435	405

* See the Material and Methods section for abbreviations.

Field sampling. In every study plot 35 sampling quadrats (20 × 50 cm) were studied. The bryophyte species composition, species coverage, and the thickness of living and dead parts of bryophytes were recorded for every quadrat. For 13 quadrats on each plot the weight of bryophytes by species and the mass of the soil O horizon (g/m^2) were measured.

Multivariate analysis. Cluster analysis was used for data processing. The bryophyte synusiae were selected by the minimal variance technique and Euclidean distance as a measure of similarity. Further, the similarity of study plots was estimated by the Canberra coefficient as a universal tool for comparing the differences between characteristics. The farthest neighbour clustering technique was used for grouping synusiae.

DISCUSSION

As a result of the multivariate analysis six bryophyte synusiae were established: *Hylocomium splendens*, *Dicranum polysetum*, *Ptilium crista-castrensis*, *Dicranum polysetum–Pleurozium schreberi*, *Pleurozium schreberi*, and *Pleurozium shreberi–Hylocomium splendens*. The hierarchy of similarity of these synusiae is shown in Fig. 1 and the most important characteristics of the bryophyte synusiae are given in Table 4. Figure 2 shows the synusial structure (percentage of selected synusiae) of the bryophyte cover on study plots.

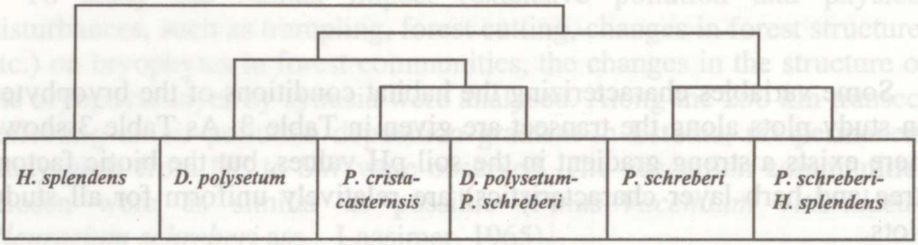

Fig. 1. Bryophyte synusiae in Scots pine forests along the air pollution deposition gradient established by cluster analysis.

Table 4

Characteristics of the bryophyte cover in the studied synusiae

Variables	Synusia*					
	X	Z	P	Y	V	R
Mean coverage, %	81.6	67.6	89.9	93.4	96.9	88.6
Number of species including macrolichens and herbs	22	35	8	15	7	13
Frequency in plots, %	25	27	9	18	5	16
Thickness of living parts, cm	2.6	3.1	2.9	3.0	3.4	3.3
Thickness of dead parts, cm	2.1	2.2	2.2	2.4	2.8	2.4
Thickness of soil O horizon, cm	6.2	5.7	6.1	7.2	9.2	7.1
Biomass of bryophytes, g/m^2	264.2	272.2	540.8	341.2	307.5	226.7
Mass of soil O horizon, g/m^2	6325.0	6920.0	5200.0	7031.1	7335.8	5241.5

* See the Discussion section for the names of the synusiae.

To study the structure of the bryophyte cover in the study plots, the thickness of the living and dead parts of bryophytes, the biomass of bryophytes, the thickness and the mass of the soil O horizon were measured. The results of the measurements are presented in Table 5. These data show that the coverage (%) and thickness (cm) of the bryophyte layer are almost the same along the transect, but the biomass of the bryophyte layer (g/m^2) has a tendency to increase from the polluted NE to the unpolluted SW. The mass of the soil O horizon varies between the plots and is related more with the soil water regime than with the pollution stress. The thickness of the soil O horizon has a strong tendency to increase from NE to SW.

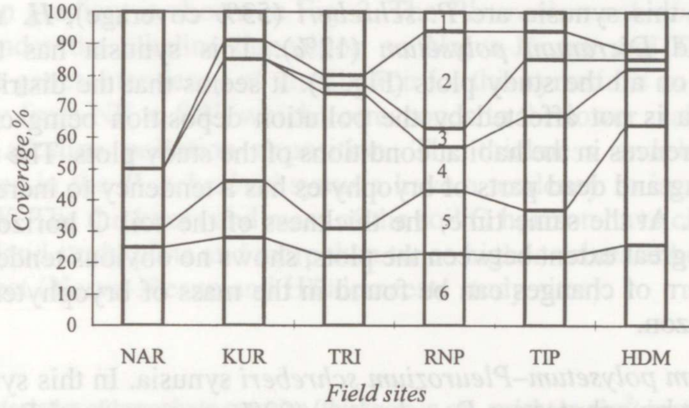

Fig. 2. Frequency of different bryophyte synusiae in the bryophyte layer on the study plots. 1, *Hylocomium splendens*; 2, *Dicranum polysetum*; 3, *Ptilium crista-castrensis*; 4, *Dicranum polysetum–Pleurozium schreberi*; 5, *Pleurozium schreberi*; 6, *Pleurozium shreberi–Hylocomium splendens*. For all abbreviations of the study plots refer to the Material and Methods section.

Table 5

Average characteristics of the bryophyte cover on study plots

Variables	Study sites*					
	NAR	KUR	TRI	RNP	TIP	HDM
Mean coverage, %	75.8	70.9	75.3	90.4	90.6	91.2
Thickness of bryophytes living parts, cm	2.0	2.0	2.9	3.5	3.9	3.4
Thickness of bryophytes dead parts, cm	1.2	1.5	2.2	3.0	3.3	2.5
Thickness of soil O horizon, cm	5.9	3.0	4.7	8.8	8.5	8.3
Biomass of bryophytes, g/m^2	175.4	230.5	221.5	355.8	484.8	329.8
Mass of soil O horizon, g/m^2	8350.0	5589.5	4903.0	8064.0	5704.0	7391.1

* See the Material and Methods section for abbreviations.

To study the changes in the bryophyte layer due to the human impact, we followed its structural changes by synusiae (Table 6).

1. *Hylocomium splendens* synusia. The bryophytes cover is almost completely formed by *H. splendens* (coverage 81%), to some degree also *Pleurozium schreberi* (4%) occurs. This synusia is more frequent on study plots in NE Estonia (Fig. 2). This area is heavily polluted by alkaline dust deposition. The thickness of the living part of bryophytes is almost the same in all study plots, with a slight decrease recorded at Narva-Jõesuu and Triigi. The thickness of the soil O horizon has a strong tendency to increase along the transect from NE to SW.

2. *Pleurozium schreberi–Hylocomium splendens* synusia. The dominating species in this synusia are *P. schreberi* (53% coverage), *H. splendens* (14%), and *Dicranum polysetum* (12%). This synusia has the same frequency on all the study plots (Fig. 2). It seems that the distribution of the synusia is not affected by the pollution deposition being caused by some differences in the habitat conditions of the study plots. The thickness of the living and dead parts of bryophytes has a tendency to increase from NE to SW. At the same time, the thickness of the soil O horizon, which varies to a great extent between the plots, shows no obvious tendency. The same pattern of changes can be found in the mass of bryophytes and the soil O horizon.

3. *Dicranum polysetum–Pleurozium schreberi* synusia. In this synusia the dominating bryophytes are *D. polysetum* (22% coverage) and *P. schreberi* (19%). Several epigeic lichen species (*Cladina* and *Cetraria*, with mean coverage of 8%) were also registered as components of the epigeic cover in this synusia. The distribution of this synusia on study plots is shown in Fig. 2. The importance of this synusia in the study plots bryophyte cover varies to a great extent – from 14.3 to 42.9%, but no clear trend of changes can be pointed out. The thickness of the living part of bryophytes is significantly lower in the NE of the transect (Narva-Jõesuu and Kurtna) than in the other areas. The same tendency can be seen in the variation in bryophytes biomass. The thickness of the soil O horizon is almost the same on all the study plots, except the Rannapungerja site, where it is more than twice as thick as on the other sites.

4. *Dicranum polysetum* synusia. In the bryophyte cover *D. polysetum* is dominating (coverage 79%) but to some degree also *P. schreberi* (10%) can be found. This synusia is not very frequent on the investigated plots (9% of all the sample quadrats). It is not found in Narva-Jõesuu, but is typical of Rannapungerja and Tipu plots (Fig. 2). This can be explained by somewhat more favourable moisture conditions, although these study plots are also less impacted by air pollution deposition. The thickness of the living part of bryophytes and of the soil O horizon have a slight tendency to increase from NE to SW, but the biomass of bryophytes does not have any clear pattern of variation.

5. *Ptilium crista-castrensis* synusia. In this synusia the species *Ptilium crista-castrensis* (coverage 79%) and *P. schreberi* (10%) are dominating. The frequency of *Ptilium crista-castrensis* synusia is only 5% of all the

sample quadrats. This synusia is not recorded on Narva-Jõesuu and Kurtna study plots (Fig. 2). The frequency of *Ptilium crista-castrensis* synusia in the bryophyte cover has a tendency to increase towards the unpolluted SW direction, and the thickness and biomass of the living part of bryophytes and the soil O horizon thickness have a strong tendency to increase in the same direction.

6. *Pleurozium schreberi* synusia. The dominating species in this synusia is *P. schreberi* (85% coverage). The coverage of other species is small – less than 6%. The relative importance and distribution of this synusia along the deposition gradient is shown in Fig. 2. The *Pleurozium schreberi* synusia is rare under the alkaline deposition on Narva-Jõesuu and Triigi study sites. The general tendency of distribution for this synusia is an increasing frequency from NE to SW, which corresponds to the lower values of soil pH and alkaline pollution deposition. The thickness and biomass of bryophytes in the *P. schreberi* synusia have a tendency to increase from NE to SW. The thickness and mass of the soil O horizon have close values on the inland study plots and more than twice higher values at both ends of the transect (Narva-Jõesuu and Häädemeeste study sites).

Table 6

Characteristics of bryophyte synusiae (thickness in cm, weight in g/m^2) in study plots

Study sites*	Thickness of			Biomass of bryophytes	Mass of soil O horizon
	living parts	dead parts	soil O horizon		
Hylocomium splendens synusia					
NAR	2.1	1.1	4.6	159.0	8 186.0
KUR	4.0	2.5	2.0	231.0	5 900.0
TRI	2.5	2.0	5.7	123.0	3 863.0
RNP	3.5	1.0	7.5	422.0	3 650.0
TIP	3.8	4.0	12.5	253.0	4 750.0
HDM	4.0	3.5	10.0	172.0	5 100.0
Pleurozium schreberi–Hylocomium splendens synusia					
NAR	1.5	1.0	9.0	260.0	8 800.0
KUR	2.5	2.3	3.0	207.9	3 350.0
TRI	2.3	1.7	3.8	152.5	4 263.0
RNP	3.4	3.0	8.0	328.5	9 410.0
TIP	3.2	2.9	6.9	322.1	6 220.0
HDM	3.3	2.7	7.3	372.2	5 800.0
Dicranum polysetum–Pleurozium schreberi synusia					
NAR	2.0	1.3	6.2	128.0	8 825.0
KUR	1.5	1.3	2.8	151.0	6 880.0
TRI	4.3	2.9	4.3	374.0	5 370.0
RNP	3.5	3.5	11.3	368.0	8 017.0
TIP	4.0	2.8	5.0	277.0	6 950.0
HDM	3.1	1.4	4.5	335.0	5 480.0

Table 6 continued

Study sites*	Thickness of			Biomass of bryophytes	Mass of soil O horizon
	living parts	dead parts	soil O horizon		
		Dicranum polysetum synusia			
NAR	–	–	–	–	–
KUR	2.0	1.0	4.0	600.5	4 300.0
TRI	1.8	0.8	3.5	450.0	4 000.0
RNP	3.7	3.2	8.2	398.0	8 500.0
TIP	3.0	2.5	6.0	624.0	2 800.0
HDM	2.7	2.3	5.5	596.0	2 600.0
		Ptilium crista-castrensis synusia			
NAR	–	–	–	–	–
KUR	–	–	–	–	–
TRI	2.5	1.5	4.8	223.0	5 350.0
RNP	3.0	3.5	10.5	292.0	7 350.0
TIP	4.5	3.5	11.3	536.0	6 843.0
HDM	3.5	2.5	10.0	179.0	9 800.0
		Pleurozium schreberi synusia			
NAR	2.5	1.3	9.5	183.9	10 620.5
KUR	2.0	1.5	3.5	377.0	3 600.0
TRI	2.7	2.7	5.8	172.0	6 317.0
RNP	3.8	2.5	6.5	370.5	6 525.0
TIP	3.2	3.2	6.7	559.0	5 371.0
HDM	3.6	3.0	11.3	385.0	9 750.0

* See the Material and Methods section for abbreviations; – not recorded.

To compare the bryophyte cover of the study plots on the basis of the frequency spectra of the synusiae, the Canberra coefficient and the nearest neighbour clustering technique were used. The results are graphically shown in Fig. 3. It turned out that the most similar study plots by the bryophyte cover structure were Rannapungerja and Tipu. These two study sites and the corresponding forest field plots are located under eutrophicated conditions (Martin et al., 1996). The Kurtna and Triigi sites have a medium pollution stress. The Häädemeeste study plot is in general close to this group by bryophyte cover. The observed differences in habitat conditions are connected with the naturally acidic soil conditions, closeness of the sea, and long distance transport of air pollutants from Central Europe. The Narva-Jõesuu study plot, as shown earlier, has drastically different air pollution deposition conditions due to its location near large alkaline dust emission sources at Narva (oil-shale fired thermal power stations).

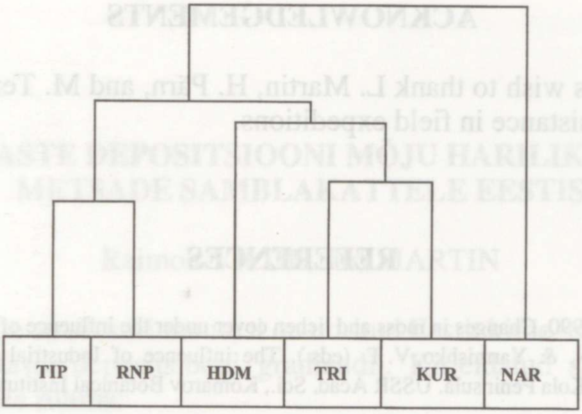

Fig. 3. Similarity of study plots calculated on the basis of bryophyte cover characteristics.

CONCLUSIONS

The bryophyte synusiae show a specific pattern of distribution depending on the level of pollution stress and differences in habitat conditions along the Estonian air pollution deposition gradient. We can divide the synusiae into two groups: (1) Synusiae whose distribution depends on the level of pollution. This group can be subdivided into 1a, the frequency is increasing in the study plots with higher pH values of the soil O horizon (*Hylocomium splendens* syn.); and 1b, the frequency is increasing on study plots with lower pH values. As a rule, these study plots are located under natural habitat conditions (typical of this type of forests) and low air pollution (*Ptilium crista-castrensis* syn. and *Pleurozium schreberi* syn.). Thus, we can say that these synusiae are sensitive to pollution. (2) Synusiae whose distribution is not directly affected by air pollution, more important are the phytocoenological, soil, and climatic factors. They are distributed more or less uniformly on all the study plots (*Pleurozium schreberi–Hylocomium splendens* syn., *Dicranum polysetum–Pleurozium schreberi* syn., and *Dicranum polysetum* syn.).

The structure of the bryophyte cover on the study plots depends on the level of pollution stress. The thickness of the living and dead parts of bryophytes is significantly lower in the NE portion of the transect. The general tendency is that it is increasing from NE to SW, that is from heavily polluted areas to unpolluted sites. The thickness of the bryophyte cover is the lowest in most synusiae at Narva-Jõesuu. The thickness of the soil O horizon in the NE study plots (Narva-Jõesuu, Kurtna, Triigi) is also notably lower than in the other plots.

The biomass of bryophytes by synusiae shows small differences between the plots. Only *Pleurozium schreberi–Hylocomium splendens* and *Dicranum polysetum–Pleurozium schreberi* synusiae show a tendency of diminishing biomass in the NE study plots.

ACKNOWLEDGEMENTS

The authors wish to thank L. Martin, H. Pärn, and M. Temina for good advice and assistance in field expeditions.

REFERENCES

Andrejeva, E. N. 1990. Changes in moss and lichen cover under the influence of air pollution. – In: Norin, B. N. & Yarmishko, V. T. (eds.). The influence of Industrial Pollution on Pine Forests of Kola Peninsula. USSR Acad. Sci., Komarov Botanical Institute, Leningrad, 133–140.

Barkman, J. J. 1958. Phytosociology and Ecology of Cryptogamic Epiphytes. Assen.

Barkman, J. J. 1968. The influence of air pollution on bryophytes and lichens. – In: First European Congress. Influence of Air Pollution on Plants and Animals. Wageningen, 197–199.

Barkman, J. J., Rose, F. & Westhoff, V. 1969. The effects of air pollution on non-vascular plants. – In: Proceedings. European Congress on the Influence of Air Pollution on Plants and Animals. Wageningen, 237–241.

Eesti paiksetest saasteallikatest õhku paisatud saastainete statistiline aruanne. 1994. aasta. 1995. Keskkonnaministeeriumi Info- ja Tehnokeskus.

Kallaste, T., Roots, O. & Saare, L. 1992. Air Pollution in Estonia 1985–1990. Environmental Report 3. Environmental Data Centre, National Board of Waters and the Environment, Helsinki.

Karofeld, E. 1994. Human impact on bogs. – In: Punning, J.-M. (ed.). The Influence of Natural and Anthropogenous Factors on the Development of Landscapes. Publ. Inst. Ecol., Estonian Acad. Sci., 133–149.

Laasimer, L. 1965. Eesti NSV taimkate. Valgus, Tallinn.

LeBlanc, F. & De Sloover, J. 1970. Relation between industrialization and the distribution and growth of epiphytic lichens and mosses in Montreal. – Can. J. Bot., 48, 1485–1496.

LeBlanc, F. & De Sloover, J. 1975. Effects of air pollutants on lichens and bryophytes. – In: Mudd, J. B. & Kozlowski, T. T. (eds.). Responses of Plants to Air Pollution, Academic Press, New York, 237–272.

Manning, W. J. & Feder, W. A. 1980. Biomonitoring Air Pollution with Plants. Appl. Science Publ., London.

Martin, J., Aaspõllu, J., Jaenes, A., Martin, L., Mehtiyeva, N., Piin, T., Pärn, H., Tekko, S., Vilde, R. & Virolainen, V. 1994. Atmospheric pollution deposition gradient studies in Estonia. – In: Solon, J., Roo-Zielinska, E. & Butnerowicz, A. (eds.). Climate and Atmospheric Deposition Studies in Forests. IGO PAS, Warszawa, 117–135.

Martin, J., Pärn, H., Vilde, R. & Martin, L. 1996. Air pollution deposition effects on Scots pine forests vegetation structure in Estonia. – Environ. Pollut. (In press).

Rao, D. N., Robitaille, G. & LeBlanc, F. 1977. Influence of heavy metal pollution on lichens and bryophytes. – J. Hattori Bot. Lab., 72, 213–239.

Tekko, S. 1991. Bioindication of sulphur distribution in Estonia using mosses. – Proc. Estonian Acad. Sci., Ecol., **1**, 4, 179–182.

Андреева Е. Н. 1989. Изменение мохового покрова северотаежных лесов при промышленном загрязнении. Авт. дис. на соиск. канд. биол. наук. Ленинград.

Отнюкова Т. Н. 1985. Экология некоторых видов мхов напочвенного покрова в лесах Муйской Котловины (зона БАМа). – Ботан. журн., **70**, 11, 1465–1477.

ÕHU SAASTE DEPOSITSIOONI MÕJU HARILIKU MÄNNI METSADE SAMBLAKATTELE EESTIS

Raimolt VILDE, Jüri MARTIN

Samblakatte struktuuri muutusi on uuritud Eestit kirde–edelasuunaliselt läbival õhusaaste depositsiooni gradiendil. Kirjeldatud samblasünuusid jagunesid kahte rühma:

1. Sünuusid, mille esinemissagedus oli sõltuv õhusaaste depositsioonist

1a. Sünuusid, mille esinemissagedus suurenes koos mulla O-horisondi pH kasvuga;

1b. Sünuusid, mille esinemissagedus suurenes koos mulla O-horisondi pH alanemisega;

2. Sünuusid, mille levik ei ole seostatav õhusaaste depositsiooniga.

Samblakatte struktuur kirde–edelasuunalisel transektil on enamasti seotud õhu saastatusest tuleneva stressiga. Uuritud metsakoosluste samblakatte tüsedus suurenes kirdest edelasse seoses õhu saastumise vähenemisega. Sammalde elusa ja surnud osa ning mulla O-horisondi tüsedus oli oluliselt väiksem Kirde-Eestis. Samal ajal ei muutunud sünuuside kaupa analüüsitud samblakatte biomass oluliselt piki saastegradienti. Ainult mõnede samblasünuuside puhul oli võimalik täheldada sammalde biomassi vähenemist kirde suunas.