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The effects of alkaline fly ash precipitation on the *Sphagnum* mosses in Niinsaare bog, NE Estonia

Emäksisen tuhkalaskeuman vaikutus rahkasammaliin Niinsaarensuolla Koillis-Virossa

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In north-east Estonia, the precipitation of calcium-rich strongly alkaline fly ash from thermal power stations has caused significant changes in the local ombrotrophic mires. *Sphagnum* mosses disappeared from Niinsaare bog during the 1970s in the period of the highest air pollution. Their disappearance was probably caused mainly by the combination of high pH values and an increased concentration of calcium in the bog water. In Niinsaare bog, the present mean pH value of bog water is 5.3 ± 0.6 and the mean calcium concentration 11.6 ± 1.6 mg l^{-1}, compared with 3.7 ± 0.4 and 1.9 ± 0.2 mg l^{-1} in the uncontaminated Nigula bog respectively. During the last decade, following the reduction of fly ash emission, the *Sphagnum* mosses started to reappear in Niinsaare bog. Nine *Sphagnum* patches dominated mainly by *S. angustifolium, S. fallax and S. magellanicum* were studied from June 1991 to September 1995. During one year, the distance between the centre and edges of these patches increased on an average by 5.1 ± 2.7 cm and the area by $29 \pm 21.5\%$. This indicates that the degeneration of *Sphagna* in NE Estonian bogs is not yet irreversible and, by reducing the air pollution in the long term, the restoration of *Sphagnum* carpet is possible.

Key words: atmospheric pollution, degeneration and recurrence of *Sphagna*, ombrotrophic mire

INTRODUCTION

The disappearance of *Sphagnum* mosses from bogs in industrial areas started ca. 150 years ago (Tallis 1964, Adams & Preston 1992) and still continues. There are several studies during the last decades from North America (Gorham et al. 1984, Gignac & Becket 1986, Austin & Wieder 1987) and West Europe (Tallis 1973, Smith 1978, Woodin et al. 1987, etc.) dealing with the effects of air pollution on bogs and *Sphagnum* mosses (Ferguson & Lee 1978–1980, Ferguson et al. 1978, Press et al. 1986, Bayley et al. 1987, Aerts et al. 1992). In these papers, the degradation of *Sphagnum* is explained mainly by the high SO_2 concentration in the air and high sulphur input. The ombrotrophic mires and *Sphagna* are especially sensitive to air pollution since they receive all their nutrients from the atmosphere.

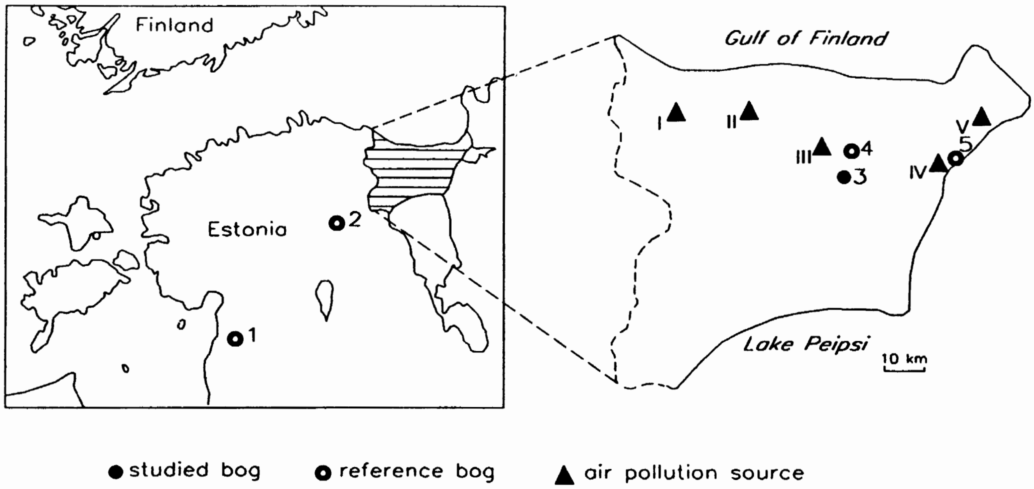

Fig. 1. General location of the study area, Niinsaare bog, reference bogs and the biggest air pollution sources in NE Estonia. 1 = Nigula bog, 2 = Männikjärve bog, 3 = Niinsaare bog, 4 = Liivjärve bog, 5 = Kõrgesoo bog. I = Kiviõli Plant of Oil Shale Chemistry, II = Kohtla-Järve Thermal Power Station and Oil Shale Chemistry Association, III = Ahtme TPS, IV = Estonian TPS, V = Baltic TPS.

Kuva 1. Niinsaarensuon (3), vertailusoiden (1, 2, 4 ja 5) sekä suurimpien saastelähteiden (I–V) sijainti.

During the last 20–30 years, significant changes have also taken place in bogs in industrial northeast (NE) Estonia, where the atmospheric pollution differs from places listed above because of the alkaline nature of the atmospheric precipitation. This paper concentrates on the disappearance and recurrence of *Sphagnum* mosses in Niinsaare bog and on the role of the changes in the atmospheric pollution and the input of strongly alkaline fly ash in this process.

MATERIAL AND METHODS

Study area

NE Estonia (Ida Virumaa county) is situated between the Gulf of Bothnia and Lake Peipsi (Fig. 1). The annual amount of precipitation is ca. 600 mm and the prevailing direction of the wind is from the south-west. *Sphagnum fuscum, S. magellanicum, S. cuspidatum, Calluna vulgaris, Empetrum nigrum, Ledum palustre, Andromeda polifolia, Vaccinium oxycoccus* and *Pinus sylvestris* (nomenclature follows Eurola et al. 1992) are dominants in the plant cover of raised bogs in unpolluted areas of the county. The pH values of the bog water in uncontaminated bogs usually vary between 3 and 4 and the mineral content is less than 2 mg l^{-1} (Valk 1988).

In 1990, the oil shale-based chemical industry and thermal power stations (TPS; Fig. 1) emitted as much as 460 thousand tonnes of pollutants into the atmosphere, mainly SO_2 (~218 thousand tn.), and oil shale fly ash (~193 thousand tn.) consisting of about 32–59% CaO, 19–34% SiO_2, 3–9% Al_2O_3, 2–6% MgO etc. (Liblik & Kundel 1995). The majority of these emissions precipitated within the radius of 20–30 km from their sources. The pH value of fly ash water-solution is ca. 12 and the monthly mean pH value of rain water in the area of Niinsaare bog, the main study area, is 5.9–7.9 (Tõugu 1987).

There are no data available from direct measurements of pollution during the highest emission period in the beginning and middle of the 1970s. The maximum concentration of fly ash computed for the above-ground air layer (the lowest air layers which have direct contact and strongest effects on the plants and ecosystems) at Niinsaare bog in 1970–1976 was approx. 600 mg m^{-3}, which decreased at the end of the 1970s to about 2–3 times less (Liblik & Rätsep 1994). The long-term average computed deposition of calcium at Niinsaare bog in 1973–1979 was about 36–73 kg ha^{-1} yr^{-1} (Kaasik 1995). The computed concentration fields are calculated using special programmes which take into consideration the height of chimneys, temperature and flow-out velocity of gases, meteorological conditions, surface profiles etc., new programmes including also the role of plant cover, open water table etc. (Liblik & Rätsep 1994, Kaasik 1995). The present maximum fly ash concentration in the above-ground air layer is ca. 60–120 µg m^{-3} and dust input ca. 50–180 kg ha^{-1} yr^{-1} (Liblik & Rätsep 1994, Liblik & Kundel 1995). The measurements of the SO_4^{2-} load in the permanent snow cover in the winters of 1984–1987 showed that the intensity of the sulphur deposition in the Niinsaare bog area was 34–41 kg ha^{-1} yr^{-1} (Voll et al. 1988), compared with about 5 kg ha^{-1} yr^{-1} in the south-west part of the county (Kaasik 1995). According to the present data, the maximum concentration of SO_2 in the above-ground air layer in the study area is ca. 150 µg m^{-3} and that of NO_x ca. 26 µg m^{-3} (Liblik & Rätsep 1994). During 1981–1990, the mean nitrogen input at Niinsaare bog was 8.9 kg ha^{-1} yr^{-1}, compared with 3.9 kg ha^{-1} yr^{-1} in central Estonia (Kallaste et al. 1992).

Niinsaare bog, with an area of ca. 70 ha and a ~5.5-m maximum thickness of peat, is surrounded by mesotrophic mires and has not been affected by such direct human activities as draining, burning or fertilizing. It has been the object of several studies from the mid 1980s. The present plant cover of this pine bog is characterized by low coverage of *Sphagnum* mosses, but the number of vascular plant species exceeds 120 (Karofeld 1994), compared with about 30 species in uncontaminated bogs (Kask 1982). For comparison, samples were collected from neighbouring Liivjärve bog and Kõrgesoo bog, which have also suffered from air pollution, and from the uncontaminated Männikjärve bog in central Estonia, and Nigula bog in south-west Estonia (Fig. 1).

Methods

Nine *Sphagnum* patches in Niinsaare bog were selected for a more detailed study of recurrence of *Sphagnum* mosses. The random selection was made from patches with clear contours, pure stands of *Sphagnum* with few vascular plants, and no barriers to radial increment such as trees, bog pools or other patches. The selected patches were situated on a *Trichophorum alpinum* lawn on a treeless area with a radius of ca. 30 m. *S. magellanicum* was dominant on six, *S. fallax* on two and *S. angustifolium* on one of the patches. In June 1991, these patches were marked with small rods in the centre and 4–5 rods around the edges of the patches. During the observation period, until September 1995, the rods were not repositioned. The distance from the centre rod to patch edges, towards the outliner rods, was measured every autumn. Based on these measurements, the shape of the patches were drawn in the field. The area of studied patches were calculated using the PC graphic desk Qtronix. Some of the patches had to be discarded from the study because of trampling or disappearance of the rods. No measurements were available in autumn of 1994 because of an early snow fall. The number of *S. magellanicum* and *S. fallax* capitula per unit area were determined from samples with an area of 18.6 cm^2 and expressed per dm^2. The dry mass (at 80°C) of *Sphagnum* was measured from these samples by weighing the uppermost 1 cm of the capitulas and they were expressed as g dm^{-2}. For determination of the ash content in *Sphagnum* mosses, reflecting the input of minerals from the air, samples were ashed 4 h at 800°C after drying.

For pH and calcium concentration measurements of the water in Niinsaare bog, the samples were collected in 1988 from the proximity of the studied *Sphagnum* patches in plastic bottles and measured with the pH meter within a couple of hours. The Ca concentration was measured by flame photometer Flapho. In the reference Kõrgesoo and Nigula bogs, the samples were taken from the central part of the massive with lawn plant communities. To study the changes in the plant cover in Niinsaare bog, reflected in the botanical composition of peat, samples were taken in 1986 from the upper 50-cm peat layer with a Russian type peat corer. The peat core was divided into subsamples according to visual differences in colour, botanical composition and degree of decomposition. The degree of decomposition (%) and botanical composition of the peat were determined more precisely microscopically (Tyuremnov et al. 1997).

RESULTS

The mean pH value of water in Niinsaare bog has increased to 5.3, compared with 3.7 in the uncon-

Fig. 2. A separate *Sphagnum magellanicum* patch on a *Trichophorum alpinum* lawn in Niinsaare bog.

Kuva 2. Sphagnum magellanicum *-kasvusto* Trichophorum alpinum *-välipinnalla Niinsaarensuolla.*

taminated reference Nigula bog, and the mean concentration of Ca has reached 11.6 mg l^{-1} (Table 1). In Kõrgesoo bog, the maxima of these values were even as high as 6.7 (mean 5.8) and 42.1 mg l^{-1} (mean 37.4) respectively.

In the middle of the 1980s, no *Sphagnum* mosses could be found in Niinsaare and in the neighbouring Liivjärve bog. This was also reflected in the botanical composition of peat. In Niinsaare bog, brown/yellow *Sphagnum* peat, dominated by *S. fuscum* and *S. rubellum*, with a 5–10% degree of decomposition, was replaced by well-decomposed (30–40%) blackish grass–dwarf shrub peat via a few millimetres' thick, mud-like interlayer at the depth of 6–10 cm.

Table 1. The pH value and concentration of Ca^{2+} (mean, standard deviation and range, n = number of samples) in the bog water in Niinsaare bog and in the uncontaminated reference Nigula bog.

Taulukko 1. Suoveden pH ja Ca-pitoisuus (keskiarvo, keskihajonta ja vaihteluväli, n = näytemäärä) Niinsaarensuolla sekä Nigulan vertailusuolla.

Bog – *Suo*	pH	Ca^{2+} mg l^{-1}
Niinsaare	5.3 ± 0.595 (4.7–5.9) n = 12	11.6 ± 1.552 (10.0–13.0) n = 5
Nigula	3.7 ± 0.364 (3.5–4.1) n = 7	1.9 ± 0.158 (1.7–2.1) n = 5

During the last 6–8 years, separate patches of *S. angustifolium, S. cuspidatum, S. fallax, S. magellanicum, S. rubellum, S. squarrosum* and *S. warnstorfii* have reappeared in Niinsaare bog. These patches have a diameter of 0.4–1.2 m and are concentrated mainly in certain areas of the bog massive, often on the *Trichophorum alpinum* lawn and on the banks of bog pools. In the *Sphagnum* patches, also *Andromeda polifolia, Calluna vulgaris, Empetrum nigrum* and *Vaccinium oxycoccus* are present. Sharp contours and steep slopes with relative elevations of 15–20 cm above the surrounding bog surface and 20–40 cm above the bog water table are rather typical for these patches (Fig. 2).

The distance between the centre and edges, as well as the area, of the studied *Sphagnum* patches increased annually. During one year, the distance between the centre and edges of the patches increased by up to 17 cm (mean 5.1 ± 2.7 cm, n = 70). No regularities were found in the direction of this widening (Fig. 3). *S. magellanicum* has the big-

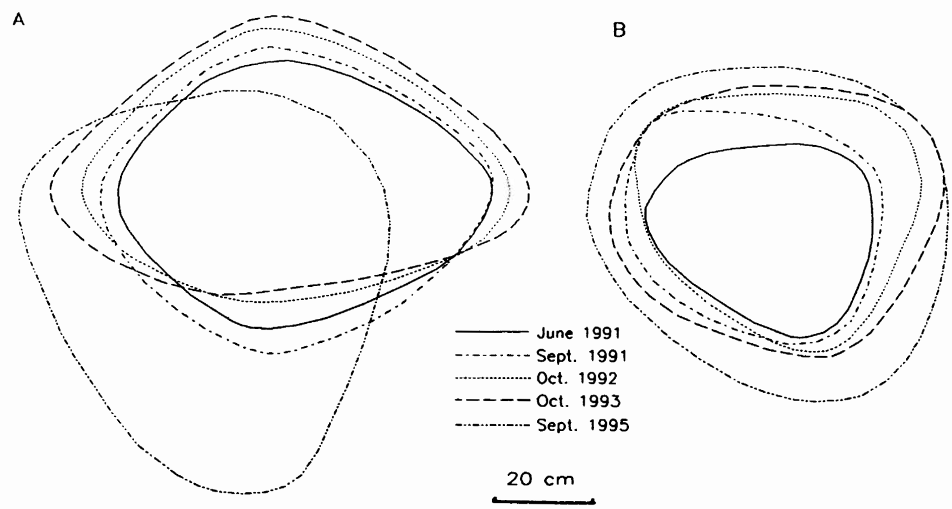

Fig. 3. The shape and area dynamics of two studied *Sphagnum* patches (A: *S. angustifolium*, no. 3 in Table 2; B: *S. magellanicum*, no. 5 in Table 2).

Kuva 3. Esimerkki rahkasammalkasvustojen muodon ja pinta-alan muutoksista (A kasvusto 3 ja B kasvusto 5 Taulukossa 2).

gest annual radial increment, 6.1 ± 3.3 cm (n = 41), compared with 5.9 ± 3.9 cm (n = 18) for *S. fallax* and 4.6 ± 1.4 cm (n = 11) for *S. angustifolium*. Because the area of patches is still comparatively small, the corresponding annual area increment can be remarkable — on an average 29 ± 21% (Table 2). In eleven cases, the distance between the centre and edges towards an outliner rod, decreased on an average by 4.4 ± 4.2 cm. Compensated by radial increment in the direction towards the other outliner rods, the area of patches reduced only in three cases during one year, on an average by 6.3 ± 3.5%.

If *Sphagnum* stems usually have one or two capitula, then on expanding patches in Niinsaare bog the plants with 4–5 capitula are not rare. The results of the *Sphagnum* shoot-density measurements and dry mass of the uppermost 1 cm of capitula in Niinsaare bog are given in Table 3. In the middle of the 1980s, the mean ash content of *S. magellanicum* in Niinsaare bog was 4.9% (± 0.7, n = 13), compared with 2.6% (± 0.6, n = 9) in September 1995 and 1.6% (± 0.5, n = 12) on an average in the reference uncontaminated bogs. But in Kõrgesoo bog, at a distance of only ca. 2 km from the Estonian TPS, the maximum ash content of *Sphagnum* reached a maximum of 15.2% (mean 12.7 ± 1.8).

DISCUSSION

We do not have any results of pH value and chemical concentration measurements of the bog water

Table 2. The area (dm^2) of the studied *Sphagnum* patches in 1991–1995. Nos. 1–2 *S. fallax*, no. 3 *S. angustifolium*, nos. 4–9 *S. magellanicum*.

Taulukko 2. Tutkittujen rahkasammalkasvustojen pinta-ala (dm^2) vuosina 1991–1995. Kasvustot 1–2 S. fallax, *3* S. angustifolium, *4–9* S. magellanicum.

	1	2	3	4	5	6	7	8	9
June 1991	44.8	46.5	32.7	29.1	14.8	20.6	45.2	12.3	12.6
September 1991	51.3	59.9	38.4	29.9	21.3	29.2	60.5	23.5	18.9
October 1992	59.5	63.1	37.1	36.2	25.0	–	–	–	20.7
October 1993	56.4	71.6	41.6	47.1	31.4	–	–	–	34.5
September 1995	53.7	–	46.3	–	42.6	–	–	–	–

in Niinsaare bog before the atmospheric pollution started. However, the Niinsaare is an ombrotrophic raised mire where, as documented by the botanical composition of peat, the plant cover was dominated by *Sphagnum* species typical for bogs, so we can presume that the ecological conditions in Niinsaare bog were, at least up to the 1960s, similar to those in the uncontaminated reference bogs at present. The increase in pH value and Ca concentration in the bog water in Niinsaare bog is caused mainly by the strongly alkaline Ca-rich fly ash deposition from the air. In laboratory tests, $Ca(OH)_2$ and $CaCO_3$ have been found to be the most effective chemicals to increase the pH value and Ca concentration in bog water (Sanger et al. 1993), and a high correlation between the CaO content and pH value of bog water is recorded (Nikonov 1957).

There can be several reasons for the degeneration and disappearence of *Sphagnum* mosses from Niinsaare bog. Their disappearance from bogs in industrial areas is often explained by a high SO_2 concentration in the air and sulphur input. However, we do not know the exact level of sulphur input which could be lethal for *Sphagnum.* It is believed that the maximum SO_2 concentration in the South Pennines from the beginning of the century to the 1950s was about 300 mg m^{-3}, whereas laboratory experiments show a clear reduction in *Sphagnum* growth at an SO_2 concentration of 131 mg m^{-3} (Woodin et al. 1987). The SO_2 mean concentration in the South Pennines in 1979–1980, about 47 mg m^{-3}, was insufficient to kill the *Sphagnum* (Woodin et al. 1987). The present calculated maximum SO_2 concentration in the air in the area of Niinsaare bog is about 130–150 mg m^{-3} (Liblik & Rätsep 1994) and it was much higher in the 1960s and 1970s. However, the toxic effect of SO_2 on *Sphagnum* in NE Estonia was probably reduced by the alkaline nature of atmospheric deposition, high pH values of rain and bog water (cf. Ferguson & Lee 1979), and therefore the disappearance of *Sphagnum* could not be caused by sulphur pollution alone.

The *Sphagnum* mosses are also sensitive to high nitrogen concentration in air (Press et al. 1986). Jauhiainen et al. (1992) found that the present annual nitrogen input in South Finland, ca. 6 kg ha^{-1}, seemed to be optimal for *S. fuscum* and *S. angustifolium* growth. According to Bernes (1994), to help preserve bogs, the annual nitrogen input in Sweden should not exceed 5–10 kg ha^{-1}, but Twenhöven (1992) suggested that 10–30 kg ha^{-1} is already the critical load for bog ecosystems. It is believed that the present annual nitrogen input in the South Pennines, approx. 32 kg ha^{-1}, is preventing the recurrence of *Sphagnum* after the decrease in sulphur input (Woodin et al. 1987). The present annual nitrogen deposition in NE Estonia, approx. 9 kg ha^{-1}, exceeds the above-mentioned loads in South Finland and Sweden, but because it is not as high as the present input in the South Pennines, it is unlikely that it is the major factor here causing the disappearance of *Sphagnum.*

The main reason for the disappearance of *Sphagnum* from some bogs in NE Estonia is probably the increased precipitation of strongly alkaline calcium-rich oil shale fly ash. *Sphagnum* mosses are usually unable to grow under conditions where the pH value of the bog water exceeds 5.5 (Botch & Masing 1979, Clymo & Hayward 1982). However, Clymo (1973) and Clymo and Hayward (1982) reported that most *Sphagnum* species can grow at either a high pH value or a high Ca concentration in bog water, but the combination of these high values is lethal for most of

Table 3. The *Sphagnum* shoot density and dry mass of the uppermost 1 cm of capitula (mean, standard deviation and range, n = number of samples) in Niinsaare bog.

Taulukko 3. Rahkasammalten versotiheys ja latvuksen (1 cm) kuivamassa (keskiarvo, keskihajonta ja vaihteluväli, n = näytemäärä) Niinsaarensuolla.

	Shoot density, n dm^{-2}	Dry mass, g dm^{-2}
Sphagnum magellanicum	162 ± 22.059 (111–217) n = 14	1.95 ± 0.437 (1.47–2.78) n = 14
Sphagnum fallax	160 ± 53.493 (85–281) n = 10	1.75 ± 0.262 (1.32–2.02) n = 10

the species. In their laboratory tests, the growth of most of the studied *Sphagnum* species were strongly reduced when the pH value of bog water exceeded 5.5 and the Ca concentration 20 mg l^{-1}. We don't know the pH and Ca concentration values in Niinsaare bog during the maximum air pollution period, but even at present, the pH value of the bog water is up to 5.9 and the concentration of Ca is as high as 13 mg l^{-1}. The toxic influence of Ca input by liming on blanket bogs and *Sphagnum* has also been observed in North Wales (MacKenzie 1992). However, according to Brehm (1970) and Touffet (1971), the essential components of fly ash — Na^+ and K^+ — may have an even bigger role than Ca^{2+} in reducing the growth of *Sphagnum* mosses.

The deposition of fly ash reflected also in the increased ash content of *Sphagnum* mosses in Niinsaare and neighbouring bogs, compared with that of uncontaminated bogs. Fly ash also has a physical influence on plants, covering the leaves with dust and clogging the leaf pores, thus reducing the activity of photosynthesis and water exchange (Farmer 1993).

The replacement of *Sphagnum* peat with grass–dwarf shrub peat has followed soon after a sharp increase in the nutrient concentration in peat, at the depth of 12–13 cm, dated back to the beginning of the 1960s (Punning et al. 1987). Therefore the beginning of the increase in the nutrient concentration in peat is most probably caused by the activation of the Ahtme TPS in 1954, and the sharp increase by the activation of the more powerful Baltic TPS in 1959. The first changes in the botanical composition of peat occurred some 5–6 cm higher than changes in the concentration of chemical elements. It can be explained by the buffering capacity of peat and the broad ecological amplitude of plants. After the disappearance of *Sphagnum* mosses, some parts of the bog surface probably remained for some years without plant cover before the pioneer plant species started to colonize these bare peat areas. Due to the increased pH value and temperature of dark bare peat, the decomposition processes were accelerated during this period and a few millimetres' thick layer of well-decomposed mud-like peat was formed.

The recurrence and widening of *Sphagnum* patches in Niinsaare bog during the latest 6–8 years is most probably due to the ~20-fold reduction in fly ash emission from the nearby Ahtme TPS at the end of 1970s, as a result of the installation of electric dust-catching filters, combined with a reduction in the capacity. Taking into account the present radius of *Sphagnum* patches and their mean annual radial increment, they had to start to grow approximately 16(12–23) years ago — in the beginning of 1980s. But the radial increment differs between years and therefore these calculations are not precise. According to our observations, the very first *Sphagnum patches* appeared in Niinsaare bog only in the middle of the 1980s. They are located often on the shores of bog pools where the aeration of bog water is better and where the water table of nutrient-rich bog water with a high pH value is lower than in the surroundings, so the mosses are more dependent on the now relatively cleaner rain water. *S. magellanicum,* which has the biggest annual radial and area increment, seems to be the most successful *Sphagnum* species in Niinsaare bog at present. Because of the relatively short observation period and different representation of *Sphagnum* species in this study, we can not make final conclusions on the relationship between the widening of *Sphagnum* patches and different species or years. The reduction in the distance between centre and edges, and the area of the studied *Sphagnum* patches, are mainly caused by trampling. In Liivjärve bog, which is situated much closer to the Ahtme TPS, only a few early *Sphagnum* patches are starting to reoccur.

The mean density of *Sphagnum magellanicum* shoots in Niinsaare bog, 162 per dm^2, is almost 3 times lower than that in Männikjärve bog (450). A separate study must be done to find out the possible reasons for this. The mean dry mass of the uppermost 1 cm of *S. magellanicum* capitula, 1.95 g dm^{-2}, is higher than the corresponding number, 1.51 g dm^{-2}, in Männikjärve bog. This difference might be caused by increased mineral (ash) content of *Sphagnum* in Niinsaare bog, due to the fly ash deposition.

Nevertheless, the conditions in Niinsaare bog are not yet suitable for a number of typical ombrotrophic *Sphagnum* species. From the species present, only *S. magellanicum, S. cuspidatum* and *S. rubellum* are ombro-oligotrophic, whereas *S. squarrosum* and *S. warnstorfii* are meso-eutrophic and *S. angustifolium* is indifferent or mesotrophic

(Masing & Trass 1955, Lange 1982, Eurola et al. 1992). *S. fallax* seems to be the most tolerant species in relation to various types of air pollution (Ferguson et al. 1978, Woodin et al. 1987).

CONCLUSIONS

From the example of changes in NE Estonia bogs, we can realize that not only the acid, but also the alkaline precipitations, could be lethal for *Sphagnum* mosses. If air pollution is not reduced, the buffering capacity of bogs will become exhausted and changes similar to those described in Niinsaare bog can occur over a much wider area. Based on the last few years' recurrence and widening of *Sphagnum* patches in Niinsaare bog, we can conclude that the above-described degeneration of *Sphagnum* is not yet irreversible. By reducing the atmospheric pollution it is still possible to stop this process and in the long term even to restore the *Sphagnum* carpet of bogs.

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TIIVISTELMÄ:

Emäksisen tuhkalaskeuman vaikutus rahkasammaliin Niinsaarensuolla Koillis-Virossa

Rahkasammalet alkoivat kadota teollistuneen Länsi-Euroopan soilta noin 150 vuotta sitten. Viime vuosikymmenien aikana on merkittäviä muutoksia tapahtunut myös Koillis-Virossa, missä palava kivi-teollisuus ja voimalaitokset päästivät ilmakehään noin 460 tuhatta tonnia saasteita vuonna 1990 (Kuva 1). Huomattavin osa saastekuormasta on emäksistä palavan kiven lentotuhkaa.

Rahkasammalpeitettä sekä suoveden happamuutta ja kalsiumpitoisuutta tutkittiin Niinsaarensuolla (pinta-ala n. 70 ha, turpeen paksuus suurimmillaan 5,5 m), joka ei ole ollut muun ihmisperäisen toiminnan (ojitus, polttaminen, turpeennosto, kydötys) vaikutuksen alaisena. Rahkasammalet katosivat Niinsaarensuolta 1970-luvulla saastelaskeuman ollessa suurimmillaan. Tärkein syy tähän oli luultavasti suoveden korkea pH ja Ca-pitoisuus. Niinsaarensuolla nykyinen suoveden pH oli 5,3 ± 0.6 ja Ca-pitoisuus 11,6 ± 1,6 mg l^{-1} (Taulukko 1), kun vastaavat arvot Lounais-Virossa sijaitsevalla Nigulan vertailusuolla olivat 3,7 ± 0,4 ja 1,9 ± 0,2. Viime vuosikymmenen aikana, kun lentotuhkapäästöt vähenivät uusien suodattimien ansiosta, rahkasammalet ilmestyivät uudelleen Niinsaarensuolle (Kuva 2). Yhdeksän *Sphagnum angustifolium*in, *S. fallax*in ja *S. magellanicum*in vallitseman rahkasammalkasvuston laajenemista seurattiin kesäkuusta 1991 syyskuuhun 1995. Kasvustojen pinta-ala laajeni vuosittain keskimäärin 29 ± 21% (Taulukko 2, Kuva 3). Tämä osoittaa, että

rahkasammalten taantuminen Koillis-Viron soilla ei ole peruuttamatonta, vaan saastepäästöjen vähentämisen jälkeen pitkällä aikavälillä rahkasammalkasvustojen uudelleenkolonisaatio tai ennallistaminen on mahdollista.

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