Changes in Understorey Vegetation of Scots Pine Stands under the Decreased Impact of Acidifying and Eutrophying Pollutants

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Abstract

Understorey vegetation of Scots pine (*Pinus sylvetris* L.) forests subjected to intense air pollution stress in the impact zone of one of the largest air pollution sources in central Lithuania – nitrogen fertilizer plant *Achema* – were studied in 31 sample plots first in 1988 and again in 2004. A recovery of the vegetation was observed since the first sample time and interpreted as due to a distinct reduction of emission of nitrogen and sulphur oxides. Study stands were 85-100 years old with vegetation assigned to the *Vaccinio-myrtillosa* site type. Species which occurence changed little (*Vaccinium myrtillus*, *Pteridium aquilinum*) and increased in occurence (*Trientalis europaea*, *Luzula pilosa*, *Vaccinium vitis-idaea*, *Melampyrum pratense*) were typical of site type species. During the study period nitrophilous species with indicator values for nitrogen ≥6 decreased in occurence. In 1988 nitrophilous plants comprised 58% of all herbaceous cover, while in 2004 only 21%. According to the unweighted Ellenberg indicator values the stands had become darker and less acidic. A significant decrease in nitrogen indicators was observed in 2004. The process of ground vegetation recovery was documented in terms of an increase in keystone species (*Vaccinium myrtillus*, *V.vitis-idaea*) and a reduction of nitrophilous species (*e.g. Rubus idaeus*).

Key words: acidification, nitrogen deposition, Ellenberg indicator values, understorey vegetation, Scots pine stands

Introduction

Decline of forest tree vitality is considered as the most prominent effect of atmospheric deposition in terrestrial ecosystems. Besides, atmospheric deposition is also held responsible for changes in the composition of ground vegetation (Binkley and Högberg 1997, Bobbink *et al*. 1998). Several studies relate changes in forest plant species composition to the impact of air pollution and deposition of pollutants (Falkengren-Grerup 1986, Falkengren-Grerup and Eriksson 1990, Nieppola 1992, Rosén *et al.* 1992, Kellner and Redbo-Torstensson 1995, Økland and Eilertsen 1996, Brunet *et al.* 1997, Nygaard and Ødegaard 1999). Increased levels of acidifying substances and increasing soil acidity can lead to alterations in species composition and abundance. In addition, in some areas several species favoured by nitrogen have shown an increase in occurence, while species sensitive to low pH have been negatively affected (Binkley and Högberg 1997).

In Lithuania, negative effects attributable to air pollution on forests have been observed in the surroundings of industrial pollution source *Achema*. The first signs of severely damaged coniferous stands were recorded in 1972 and massive mortality of the forest was observed in 1979. At the distance of 2-3 km from *Achema* coniferous forests completely died (Armolaitis *et al.* 1999). Air pollution is considered to be the main cause of the massive forest dieback in the region that peaked at the beginning of the 1980s. Recently annual emissions of *Achema* has been much reduced and today does not exceed 5-7 thousands tons, as compared to 40 thousands at the beginning of the 1980s.

Most of the forest of this region grow on naturally nitrogen poor soils and have vegetation adapted to such soils. Atmospheric pollution may cause the alterations in the composition of forest communities but may also cause changes in soil nutrient levels and trees vitality. There is a relatively large number of pine stands in the surroundings of *Achema* but a detailed survey of the vegetation is still lacking. The aim of this study was to analyse changes in the vegetation that have occurred over the last 16 years in coniferous forests by pollution from *Achema*.

Material and methods

Stands of Scots pine (*Pinus sylvestris* L.) were investigated close to one of the biggest producers of nitrogen fertilisers in the Baltic – *Achema* plant that has been operating since 1965. *Achema* is situated in the central Lithuania, in Jonava city (55°05' N, 24°20' E). The main activity of the plant is the production of nitrogen fertilizers, ammonia, nitric acid, methanol, formalin, glues, carbonic acid and aluminium sulphate solution. Nitrogen fertilizers are produced by fixing nitrogen from the air. Large amount of energy is needed for this endothermic process and the main part of emission contain ammonia, sulphur, nitrogen and carbon oxides.

Air pollution is considered to be the main cause of massive forest dieback that peaked at the beginning of the 1980s. Sulphur, nitrogen and carbon oxides comprise the main part of emissions resulting from burning organic fuel (Fig. 1). A rather large quantity of ammonia and dust of mineral fertilizers were emitted into the air by producing it. The decrease in emissions was recorded since the end of the 1980s. From 1991 the total amount of pollutants decreased to only 5-7 thousands tones annually in comparison with 40th. t at the beginning of the 1980s (Juknys *et al*. 2003).

The total annual deposition of sulphur at the distance of 1-2 km from the plant comprised about 50 kg and at the distance of 20-22 km over 30 kg in 1980. Now it is reduced up to 15 and 9 kg ha^{-1}, respectively. Annual deposition of nitrogen has also decreased and it constitutes 15-17 kg ha^{-1} 20-22 km from the plant (Armolaitis 1998).

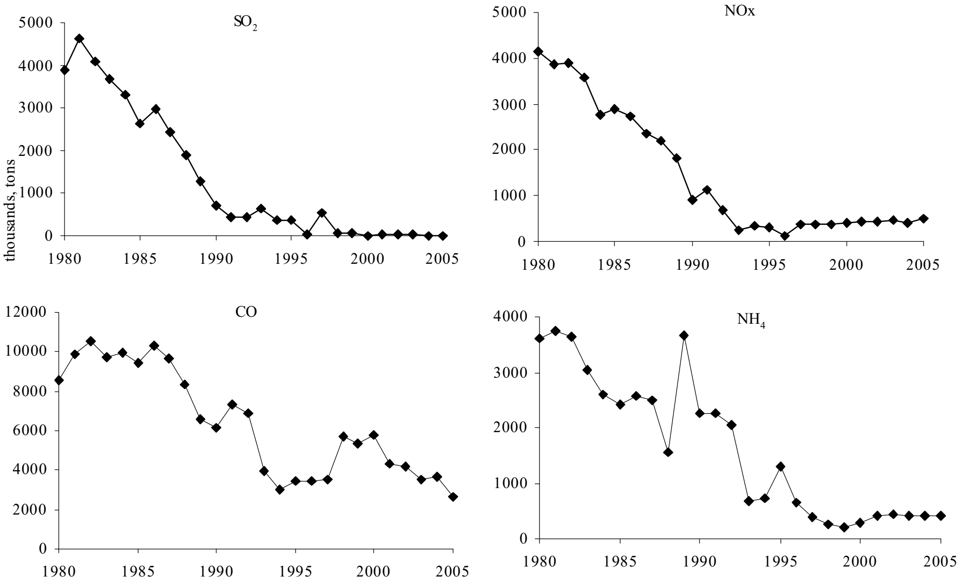

Figure 1. Annual emissions of Achema plant

The study sites were established in the prevailing wind direction from *Achema* (to the west from the plant) at a distance of 3-22 km. Vegetation data from 31 pine stands surveyed in 1987-1988 (further referred as 1988) were available (S.Karazija, unpublished data). The sites were originally established for the study of air pollution impacts on forest vitality. Stands aged 85-100 years with vegetation assigned to the *Vaccinio-myrtillosa* site type and with similar dendrometrical characteristics were preferred and reinvestigated in July, 2004.

Vegetation assessment was performed in the same stand but not exactly in the same place where the first survey was performed. On each study site sampling was performed in the systematic distributed 20 quadrates. Quadrates (1 m^2) were placed in 4 directions running north-south and east-west from the central tree. The distance between the central tree and quadrates was 4 m. The percentage cover of vascular plants (<1.5 m height) and moss was visually estimated in each sample quadrate, then the mean value was calculated for each sample plot. The vascular plant species data set used for further analysis only included non-woody plants, except for *Rubus* sp., *Vaccinium* sp. and *Calluna vulgaris*.

The frequency of each species was calculated for 1988 and 2004 as the percentage of all plots in which the species was present. Unweighted averages of the Ellenberg indicator values for light (E_L) moisture (E_F), pH (E_R) and nitrogen (E_N) were calculated and used as an estimate of the environmental variables in the plots (Weber 1991, Ellenberg 1991).

The significance of changes in species variables between the years was tested with the non-parametric Kruskal-Wallis and Wilcoxon's paired signed-ranks tests. Ordinations are applied to determine the difference between the groups of old and new study sites and the influence of environmental factors (general temporal change and forest age) on the vegetation. Principal Component Analysis (PCA) and Redundancy Analysis (RDA) are applied using CANOCO.

Results

Changes in the number of species and frequency

A comparison of the number of species per sample plot between the two years (1988 and 2004) showed that the difference was not significant (T= 0.38, $p>0.05$; Fig. 2). There was a tendency for a higher mean species number in 2004, as compared to 1988 (12.6 and 14.4, respectively). The averages of species number were also higher in 2004 than in 1988 (22 and 20 species, respectively) but the difference was not significant ($p>0.05$; Fig. 3). The number of herbaceous and moss species was also slightly larger in 2004 than between sampled years ($p>0.05$).

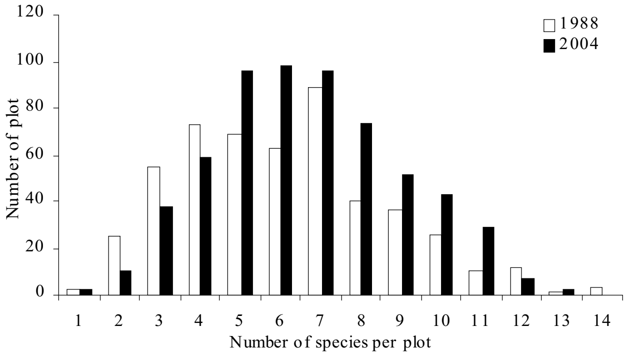

Figure 2. Changes in the distribution of numbers of species per plot between 1988 and 2004

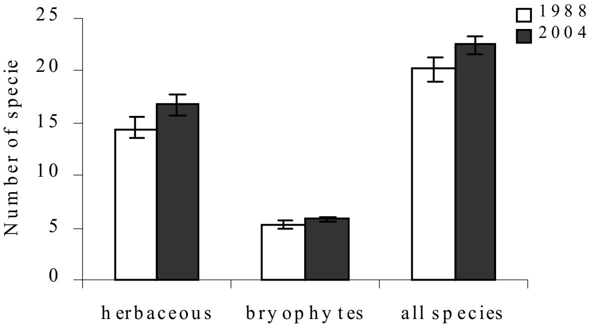

Figure 3. Number of all species, herbaceous and bryophytes between 1988 and 2004

The basic characteristics of ordination results are resumed in Table 1. A comparison of eigenvalues of the first axis (λ_1) from the PCA and RDA_{time} showed that about 3/5 (59%) of the vegetation variability along the main floristic gradient could be attributed to a temporal change. Permutation test of the constrained axis was highly significant. Species variability was not considerably related to a change in forest age (RDA_{age}, $p>0.05$).

Table 1. Results of ordinations. N_{sp} denotes number of sample plots, N_{spec} – number of species. λ_1 and λ_2 were eigenvalues of the first and the second ordination axes, in %. *F* was the F-statistics of Monte Carlo permutation test with its p-value

Analysis	N_{sp}	N_{spec}	Environmental variables	$_1$	$_2$	F	p
PCA	62	106	-	24.5	14.8	-	-
RDA_{time}	62	106	time	14.5	15.1	4.8	<0.01
RDA_{age}	62	106	age	4.1	20.2	1.5	0.13

Changes in plant species frequency between 1988 and 2004 were assigned to such groups: extinct species (frequency -100%), decreased species (-90% – -10%), no or a slight change (-10% – 10%), increased species (11–99%) and newly appeared species (100%). While there were almost a half of species (48 species of all 98) which frequency increased or appeared for the first time on the study sites, the third part of species (37%) decreased or extinct (37 species). There were 12 nitrophilic species which frequency decreased and 11 species which frequency showed little or no change over the study years.

RDA_{time} showed the same disproportion between the number of species that had declined (left side) and those that had increased (right side), see Figure 4. The species that had increased were typical of *Vaccinio-myrtillosa* site type – *Vaccinium myrtillus*, *Pteridium aquilinium*, *Trientalis europaea*, *Oxalis acetosella*, *Festuca ovina*, *Luzula pilosa*, *Vaccinium vitis-idaea*, *Calamagrostis arundinacea*, *Melampyrum pratense*, *Convallaria majalis*, *Solidago virgaurea*.

The species that had decreased most significantly between the study years were related with nutrient-rich conditions with an indicator value for nitrogen ≥6 (Weber 1991, Ellenberg 1991). Frequency of such species as *Rubus idaeus*, *Rubus caesius*, *Impatiens noli-tangere* and *Chamerion angustifolium* decreased considerably ($p<0.05$), other species also decreased but not so significantly ($p>0.05$) – *Galeopsis tetrahit*, *Stellaria media*, while the other nitrophilic species were relatively extinct – *Aegopodium podagraria*, *Epilobium montanum*.

The mean nitrophilic species frequency per sample quadrate was significantly higher in 1988 than in

2004 (85.6% and 63.8%, respectively, $p<0.01$). The mean number of nitrophilic species was also higher in 1988 comparing with that of nitrophilous species in 2004 (4.7 and 4.3, respectively) but the difference was not significant ($p>0.05$) (Fig. 5). The cover of nitrophilous plants comprised the significantly larger part of the sample quadrates in 1988 (58%) comparing with 2004 (21%) ($p<0.001$; Fig. 5).

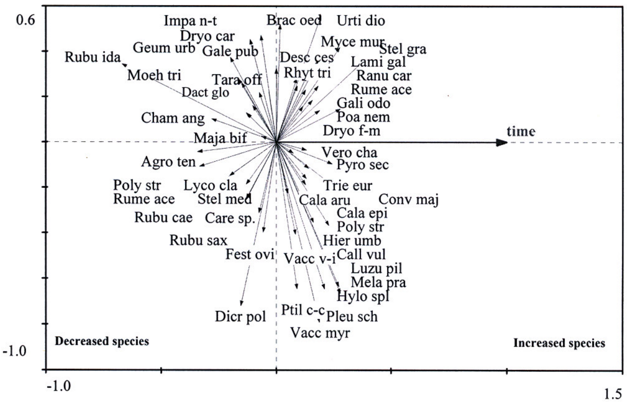

Figure 4. RDA_{time}, constrained with factor "time", reflecting the overall vegetation change. On the right side were increased species, on the left – decreased species

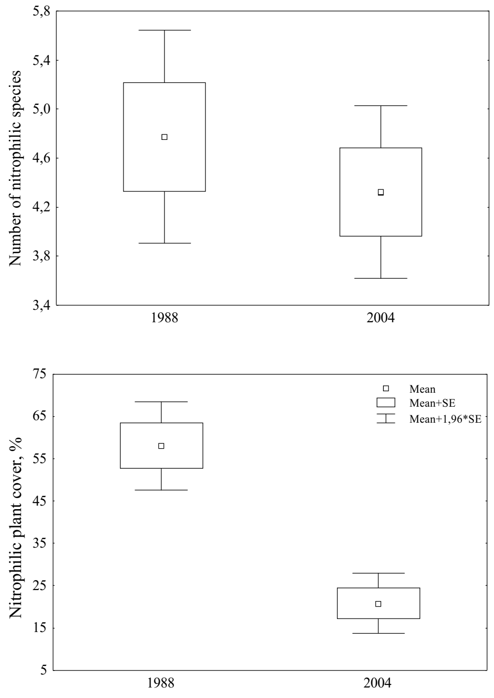

Figure 5. Mean number of nitrophilous plants and the cover of all herbaceous plants cover (%) in 1988 and 2004 in the impact zone of *Achema*

Under the acidifying and eutrophying pollutants impact bryophytes are considered as particularly sensitive to changes in atmospheric concentrations due to lack of cuticle and nutrients absorbs over all surface (Rodenkirchen 1992, Mäkipää 1995, Bates 2002, Mitchell et al. 2004). Typical for *Vaccinio-myrtillosa* site type bryophytes species change of frequency was little – *Pleurozium schreberi* (Brid.) Mitt. and *Hylocomium splendens* (Hedw.) Schimp. frequency increased only about 10%. A significant increase had been noted for *Rhytidiadelphus triquetrus* (Hedw.) Warnst., the frequency of which increased 59%. Increase in site eutrophic level is known to be negative for this species abundance and it is an indicator for nutrient-poor conditions (Kuhn *et al.* 1987).

Changes in species indicator values (E_L, E_F, E_R, E_N)

The Ellenberg indicator value for light (E_L) was lower in 2004, as compared to 1988, but the difference was not significant between the study years ($p<0.05$) (Fig. 6). The indicator values for moisture (E_F) showed only a small non-significant increase between the years ($p<0.05$; Fig. 6). Changes in E_L and E_F can be interpreted relatively easy as due to closing of the canopy and lesser substrate drying.

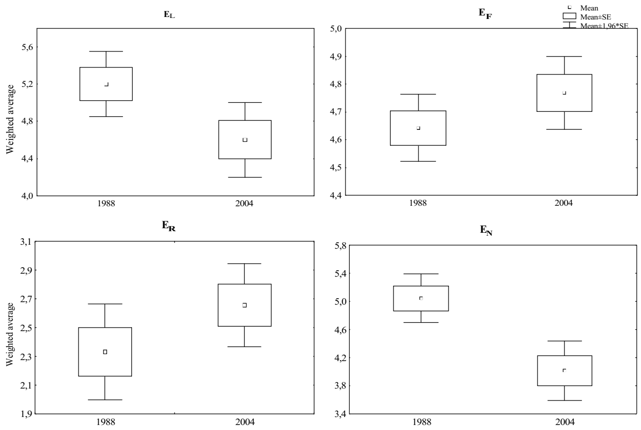

Figure 6. Distribution of indicator values for sample plots in 1988 and 2004 considering four Ellenberg indicator parameters (light - E_L, moisture - E_F, acidity - E_R, nitrogen - E_N)

The indicator values for soil acidity (E_R) increased but not significantly ($p<0.05$; Fig. 6), *i.e.* soil acidity decreased. On the contrary, indicator values for nitrogen (E_N) indicated a considerable decrease from 1988 to 2004 ($p<0.001$). This decrease was mainly due to the reduction in cover of nitrophilous plants that was dominating in 1980 but much reduced in 2004. As proven by van Dobben *et al.* (1999), E_N increases when nitrogen increases, E_R increases with liming, both decrease with acidifying almost linearly. An increase in E_R probable reflects an increase in soil calcium content. This is closest linked with the content of other cations. A decrease in E_N reflects an increase in ecosystem's productivity.

Discussion and conclusions

Since 1989, when the amount of emission greatly decreased, the conditions for different ecosystem components recovery established. It was shown by the results of comparing vegetation occurence of the first sampling in 1988 and re-sampling in 2004. Species number per sample plot increased during this period but the difference was not significant. In the sampled year of the greatest emission (1988) the most expanding species was herbaceous plants which determined the lower bryophytes species number and frequency. Species, which decreased in occurence or was not found, comprised 37% of all species and species, which frequency increased or newly appeared – the half of all species. Among the species the occurence of which decreased were 12 nitrophilic.

Species which frequency was changed slightly are typical of *Vaccinio-myrtillo* site type species (*Vaccinium myrtillus*, *Pteridium aquilinum* (L.) Kuhn), and increased in frequency (*Trientalis europaea* L., *Luzula pilosa* L. Willd., *Vaccinium vitis-idaea*, *Melampyrum pratense* L.). The frequency of species typical of *Vaccinio-myrtillo* site type as are bryophytes *Hylocomium splendens* (Hedw.) Schimp. and *Pleurozium schreberi* (Brid.) Mitt., increased about 10%. The significant increase in frequency (59%) was determined for *Rhytidiadelphus triquetrus* (Hedw.) Warnst.

One of the prominent changes was a decrease in occurence of *Rubus idaea*. Also some other nitrophilous species (*Rubus caesius*, *Impatiens noli-tangere*, *Chamerion angustifolium*) decreased in occurence. During the study period the frequency of nitrophilous plants with indicator values for nitrogen ≥ 6 (according to Ellenberg 1991) decreased. In 1988, cover of nitrophilous plants comprised 58% of all herbaceous cover, while in 2004 it constituted only 21%. Non-typical for *Vaccinio-myrtillo* site type species - *Aegopodium podagraria* L. and *Epilobium montanum* L. - were not found in 2004. The decrease in nitrogen deposition appears as the most plausible explanation for these changes. The amount of NO_3-N in the mineral soil solution on average decreased 5 times, NH_4-N - about 2 times between 1988 and 1999 (Armolaitis and Stakenas 2001). These above mentioned decreasing species are typical of nitrogen rich ecosystems and have previously been shown to increase in nitrogen treatment experiments (van Dobben *et al.* 1998). In addition, the same species are known to have increased in many regions, most plausible as an effect of increased nitrogen deposition (Falkengren-Grerup 1986, Thimonier *et al.* 1992).

An explanation for the increase in nitrophilous species in the first survey might be that atmospheric pollution has facilitated the recovery of damaged tree crowns that in turn have caused a decreased light flux to the forest floor. The significant decrease in indicator values for light confirmed this indirect effect of increased shade. The forests surrounding *Achema* were particularly affected in the beginning of the 1980s through large needle losses and death of trees. Needle losses have resulted in more organic matter and more mineral nutrients returning to the soil and in a considerable increase in the amount of light reaching the ground layer, thereby changing the conditions for interspecific competition. These changes, favourable to the ground vegetation, may, in turn, lead to an increase in biological humus activity and to an increase in organic matter mineralization (Kenk and Fischer 1988). The growth of the tree layer may suppress the ground vegetation by increasing shading and this might be unfavourable for light demanding species that were previously positively affected by defoliation (Vacek *et al.* 1999). A decrease in indicator values for light in forests between two points in time was also observed by Thimonier *et al.* (1992) and Diekmann *et al.* (1999).

Some nitrogen fertilization experiments in coniferous forests have shown both positive and negative responses for dwarf shrubs. However, the initial site conditions were very important. Dwarf shrubs responded positively only at the poorer sites where there was no competition from grasses (Kellner 1993). In the present study, a positive response was documented. The frequency of both *Vaccinium myrtillus* and *V. vitis-idaeus* increased. One explanation for that may be that reduced nitrogen level in combination with reduced competition from grasses and herbs positively affected the main forest type dwarf species (Nygaard 1994, Aerts and Berendse 1988). In fertilization experiments the responses of these species have been mainly in terms of changes in competitive relationships (Persson 1981, van Dobben *et al.* 1998, Vacek *et al.* 1999). Another explanation may be that ericaceous species are known to have a poor capability to utilize nitrate (Högberg *et al.* 1990).

It is clear from the study that the species composition of the ground layer of forests in the surroundings of Achema has undergone changes over the last 16 years. Canopy defoliation has decreased at the same time as the frequency of nitrophilous species has been reduced. Simultaneously, forest keystone species (*e.g. Vaccinium myrtillus, V.vitis-idaea*) have increased in occurence. However, further research is needed to clarify the precise relation between changes in the undergrowth, vitality of the tree layer and changes in soil chemistry.

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ИЗМЕНЕНИЕ ЖИВОГО НАДПОЧВЕННОВО ПОКРОВА В ДРЕВОСТОЯХ СОСНЫ ПРИ УМЕНШЕНИИ КИСЛОТНЫХ И ЭУТРОФИЧЕСКИХ ЭМИСИЙ

Г. Суетовиене и В. Стакенас

Резюме

Исследовались изменения растительности в сосновых насаждениях под влиянием одного из самых больших источников загрязнений в Литве – завода азотных удобрений “Ахема”. Видовой состав живого надпочвенного покрова бруснично-черничных (*Vaccinio-myrtillosa*) древостоях сосны обыкновенной (*Pinus sylvestris* L.) исследовался на восток от завода в 1988 г. и 2004 г. Исследования проводились в сосняках 85-100 г. возраста на 31 пробной площади. Установлено восстановление растительности под влиянием значительного уменьшения выбрасываемого количества азотных и серных соединений. Встречаемость типичных видов (*Vaccinium myrtillus*, *Pteridium aquilinum*) изменилось незначительно, других – увеличивалась (*Trientallis europaea*, *Luzula pilosa*, *Vaccinium vitis-idaea*, *Melampyrum pratense*). Встречаемость нитрофильных видов растений, у которых индикаторные значения азота ≥ 6, за исследованный период уменьшилась. Если в 1998 г. покрытие нитрофильных растений в среднем достигало 58% всех травянистых растений, то в 2004 г. – только 21%. По индикаторными балами Элленберга встречались более теневыносливые виды растительности, а почвы - менее кислые, и достоверно уменьшались индикаторные балы азота. Процесс восстановления объясняется увеличением обильности индикаторных видов и уменьшением нитрофилов.

Ключевые слова: древостой сосны обыкновенной, загрязнение, индикаторные балы Элленберга, живой надпочвенный покров