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Acidification and Eutrophication of Pine (*Pinus sylvestris* L.) Forests Demonstrated by Indicator Species Analysis

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The aim of the study was to estimate changes in the stand condition in the surroundings of "Achema" impact zone by species demand for environmental factors. Ground vegetation of 80-100 years old *Pinus sylvestris* L. stands attributable to *Vaccinio-myrtillosa* site type was chosen as an object. Weighted averages of indicator values for nitrogen (E_N) close to the plant decline with the distance from the emission source. The relative share of nitrogen indicating species was significantly higher in the impact zone (E_N = 2.7) than in the control (E_N = 1.5). The increased abundance of nitrogen indicators in the forest ground vegetation could partly be attributed to an increase in atmospheric nitrogen deposition in the forests. Weighted averages of Ellenberg's indicator values for soil reaction (E_R) along the study transect were not significantly correlated with the distance from "Achema". In the closest to "Achema" vicinity (2 km east and 5-8 km north-east) E_R was significantly lower in comparison to the control ($p < 0.05$). According to the indicator values for light (E_L), there were no significant differences at different distances. In comparison to the control indicator the averages for light were higher but not significantly ($p > 0.05$). In accordance with the indicator values the conclusion is drawn that in the impact zone (2-11 km) the ground vegetation of pine stands is affected due to "Achema" acidifying and eutrophying pollution.

Keywords: ground vegetation, indicator values, acidification, eutrophication, Scots pine stands.

1. Introduction

Changes in the atmosphere due to human activities have a considerable impact on many ecosystem processes. Atmospheric deposition of toxic gases, acidifying substances (sulphur and nitrogen oxides, mainly) and excessive nutrients has become a major problem. Long-term changes in vegetation are difficult to demonstrate. Vegetation changes in forests are often slow and responses of plants to chemical alterations in the soil may occur with delay. Several studies relate changes in the forest species composition to the impact of air pollution (e.g., Falkengren-Grerup 1986, Falkengren-Grerup&Eriksson 1990, Nieppola 1992, Rosén et al. 1992, Kellner&Redbo-Torstensson 1995, Økland&Eilertsen 1996, Brunet et al. 1997, Nygaard&Ødegaard 1999). Increased levels of acidifying substances and increasing soil acidity can lead to alterations in species composition and abundance. Many nitrogen indicators have shown an increase in frequency, while species sensitive to low pH may be directly negatively affected (Binkley&Högberg 1997).

Negative effects, attributable to air pollution, on forests in Lithuania were observed in the surroundings of industrial pollution source "Achema" where the dead and damaged coniferous stands have developed. Many of these forests grow in nitrogen poor habitats. Species growing there are adapted to nitrogen poor soils. Atmospheric pollution causes the alterations in the composition of forest communities but also disturbances in soil nutrient levels and changes in trees vitality (Armolaitis 1998, Armolaitis et al. 1999, Juknys et al. 2003).

Forest as a component of ecosphere is not only regulator of negative anthropogenic processes but also a responsible indicator of environmental changes. Increasing anthropogenic load related to atmospheric pollution and intensive agriculture activities in recent decades cause transformation processes of many natural ecosystems. Vegetation composition and distribution changes particularly typical of the forest ecosystems often proceed from changes in the habitat trophic extent due to anthropogenic activities. In intensively affected Germany and Czech stands the observed outspread of nitrophilic plants and gramineous invasion were related not only to environmental eutrophication due to an increase in nitrogen (N) deposition (Schmidt 1993) but also to decrease in interspecific competition due to crown rarefaction (defoliation) and tree attenuation (Steiner et al. 1998).

Recent researches related to the increased atmospheric pollution and changes in forest ground vegetation have been performed on direct plant composition along the pollutants gradients or comparison in a time scale. The other indirect evaluation of environmental changes is the estimation of indicator values of individual species. Results have shown a close link between environmental variables and Ellenberg's indicator values (Diekmann 1995, Pitcairn et al. 2002, EC-UN/ECE 2003).

Plant indicator characteristics reflect also ecological habitat conditions, therefore research in the floristical composition makes it possible to evaluate environmental conditions. Individual plant species tolerance to main ecological parameters (light, soil moisture, fertility, acidity) is used for many a long time in phytoindication. An important tool which contributed to an understanding of how the flora is affected by changes in the environment was created by H. Ellenberg (Ellenberg 1991). Six ecological factors, namely light, temperature, continentality, moisture, reaction and nitrogen, were each divided into 9 (in the case of moisture -12) so-called indicator values. A species given a low value occurs mainly where the factor is less pronounced, and vice versa, species in light class 1 prefer full shadow, 5 - half shadow, and 9 - full lights. Ellenberg's indicator values represent a set of scores for Central European species expressing the optimum requirements for light, temperature, water, etc. Ellenberg's indicators are a fundamentally quantitative expression of ecological gradients, and they summarize in a few indices the huge amount of ecological observations about plants and plant communities in Central Europe.

The research was based on the hypothesis that typical of a site type the ground vegetation subjected to the anthropogenic pollution stress was changed, and, as a consequence, main plant species disappear. The objective of the research was to characterize the current state of the forest ecosystems on the basis of their composition and the changes in ground layer species of Scots pine (*Pinus sylvestris* L.) stands under the impact of acidifying and eutrophying local pollution.

2. Methods

2.1. Study area

The study area is situated near the nitrogen fertilizers producer plant at Jonava (55°05′ N, 24°20′ E), central Lithuania. The study sites are located in Scots pine (*Pinus sylvestris* L.) stands at different distances to the east and to the north-east from "Achema". The study transects have probably been exposed to the heaviest deposition level because south-westerly winds are dominant in the area. It also was assumed that according to the changes in the soil chemistry and stands condition (Armolaitis et al. 1999), this was a deposition gradient where the impact of "Achema" pollution decreased with increasing distance from it. Apart from the pollution level, the tree stand and site type at the individual plots were originally relatively similar.

Scots pine stands near nitrogen fertilizer plant "Achema", i.e. the main local pollution source in Lithuania, were studied. The ground vegetation of Scots pine stands in the impact zones of these plants were chosen as objects of research.

"Achema" began operating since 1965. 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 fertilizer is produced by fixing nitrogen from the air. A large amount of energy is needed for this endothermic process and emission of ammonia, sulphur, nitrogen and carbon oxides comprise the main part of emission.

The entire area has been under air pollution stress since 1980 where 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, currently it was reduced up to 15 and 9 kg ha^{-1}, respectively. Annual deposition of nitrogen decreased also and it constitutes 15-17 kg ha^{-1} 20-22 km from the plant (Armolaitis 1998). Air pollution is considered to be the main cause of a massive forest dieback that peaked in the beginning of the 1980s. The total amount of pollutants decreased to only 5-7 thousand tons annually from 1980 in comparison with 40 thousand t in the beginning of the 1980s (Juknys et al. 2003).

2.2. Sampling design and vegetation analysis

The understorey vegetation was studied at the sites situated in Scots pine (*Pinus sylvestris* L.) stands at five distances (2, 4, 5, 8 and 9 km) to the east and at three distances (5, 8 and 11 km) to the north-east from the nitrogen fertilizers producer plant "Achema" in July, 2003. In each study site sampling was performed in 16 vegetation quadrates (1 m^2) laying out in fours quadrates in the direction of 0, 90, 180 and 270 azimuths from the chosen central tree. Vegetation data collected from the sample plots at 8 km distance west from the plant were used as the reference level.

The percentage cover of vascular plants (<1.5 m height) and mosses present was visually estimated in each sample quadrate, then a mean value was calculated for each sample plot. The vascular plant species data used for the further analysis included only non-woody plants, except for *Rubus* sp., *Vaccinium* sp., *Calluna vulgaris*.

2.3. Data analysis

The values of environmental variables in the plots were assessed by species analysis using Ellenberg indicator values for humidity (E_F), light (E_L), reaction (E_R), and nitrogen (E_N). Weighted averages (WA) of these indicator values were calculated according to Diekmann (1995). The comparisons of indicator values between plots from different distances were carried out by means of *t*-test for unmatched samples.

3. Results and discussion

Each study site was tested with respect to nitrogen, acidity and light preferences of the occurring species. The indicator averages for nitrogen (E_N) close to the plant were higher than those for the farther plots and decline with the distance from the emission source (Fig. 1). The weighted averages for soil nitrogen (E_N) along the study transect were not significantly correlated with the distance from "Achema" ($R^2 = 0.07$, $p > 0.05$).

A relative share of nitrogen indicating species was significantly higher in the impact zone ($E_N = 2.7$) than in the control ($E_N = 1.5$, $p < 0.05$). The increased abundance of nitrogen indicators in the forest ground vegetation could partly be attributed to an increase in the atmospheric nitrogen deposition in the forests. This phenomenon is also commonly observed in the forests of other European countries: Sweden (Falkengren-Grerup&Eriksson 1990, Falkengren-Grerup&Tyler 1991, Brunet et al. 1997), Germany (Diekmann&Dupré 1997), France (Thimonier et al. 1994), The Netherlands (van Tol et al. 1998), Belgium (Lameire et al. 2000).

Several studies on the effects of N deposition have interpreted the changes in the vegetation as an increase in "nitrophilic" species, often represented by the Ellenberg's N values (rewiev by Bobbink et al. 1996). The Ellenberg's nitrogen values did not change over time for the forests on the most acid soils, but increased for the forest on soils with the higher pH (Diekmann et al. 1999). Our results on the study sites differences in the N value are in accordance with the changes in the more acid soils – at 2-8 km east and 5-11 km north-east from the plant with acid soils according to soil chemical analysis in the surroundings of "Achema" (Armolaitis et al. 1999).

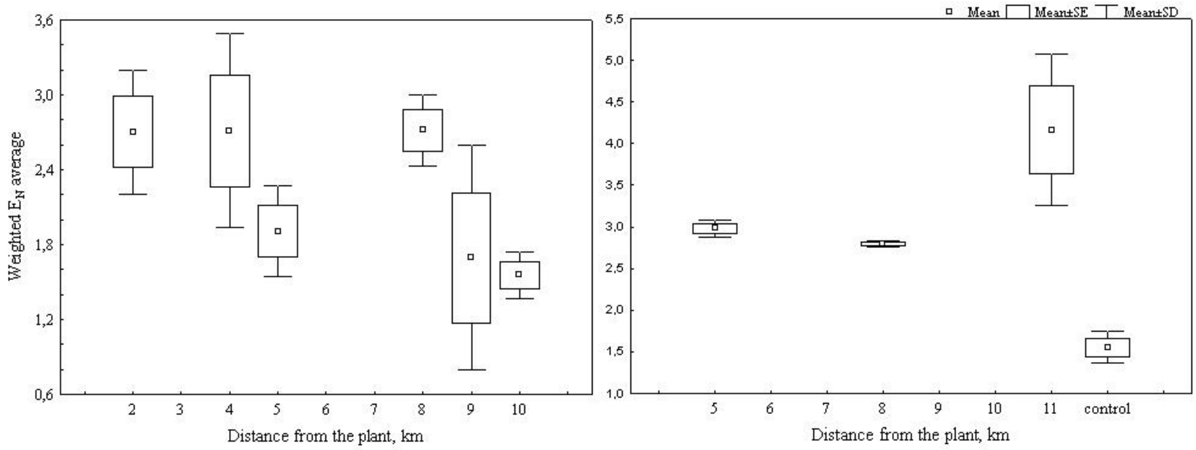

Fig. 1. Weighted averages for soil nitrogen (E_N) east (A) and north-east (B) from "Achema"

The weighted averages for soil acidity (E_R) along the study transect were not significantly correlated with the distance from "Achema" ($R^2 = 0.07$, $p > 0.05$; Fig. 2). In the closest to "Achema" vicinity (2 km east and 5-8 km north-east) E_R was significantly lower in comparison with the control ($p < 0.05$). Indicator E_R averages in the impact zone (4-9 km east) were lower in comparison with the control but the differences were not significantly different ($p > 0.05$). In the north-east direction from the plant E_R averages were significantly lower at 5 - 8 km distance but there was no difference between E_R at the farthest sample plot (11 km) and the control ($p > 0.05$; Fig. 2).

A relative share of acid soil indicating species (R = 2-3) was slightly lower in the impact zone ($E_R = 3.0$) than in the control ($E_R = 3.1$) but the difference was not significant ($p > 0.05$). Relatively low E_R averages in the impact zone of "Achema" showed the outspread of plant species preferring acid soil. It is also evident that such species constitute a more important part of the pine vegetation of reference, i.e. in the sample plot at 8 km distance west from the plant than in the impact zone downwind (east and north-east) from the plant at 8 km range.

According to the indicator values for light (E_L), there were no significant differences at different distances

(Fig. 3). In comparison with the control indicator the averages for light were not significantly higher ($p > 0.05$). Similar indicator values showed that the stands growing at different distances from the plant did not differ in crown conditions. That is the conditions for the lower field layer were similar in the canopy closure and the light intensity.

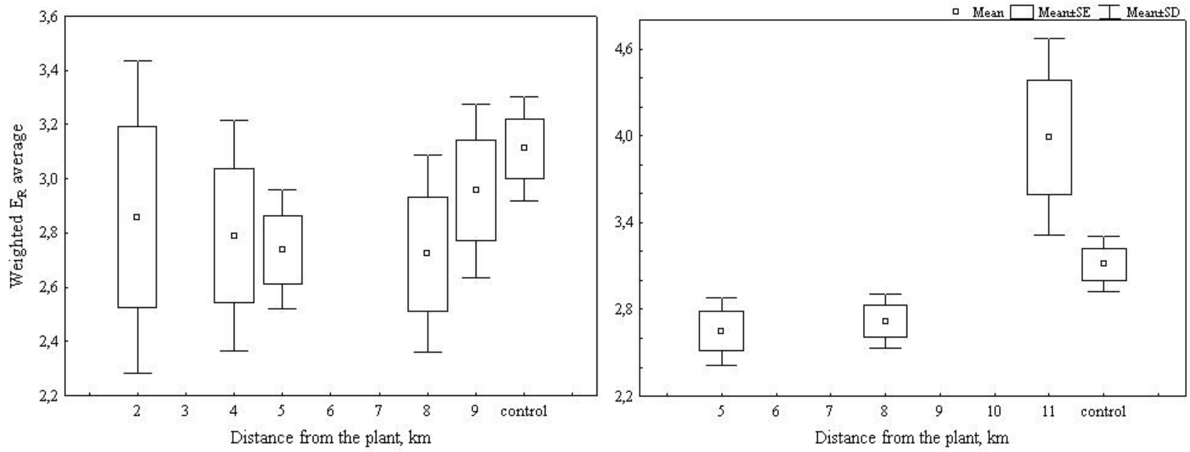

Fig. 2. *Weighted averages for soil acidity (E_R) east (A) and north-east (B) from "Achema"*

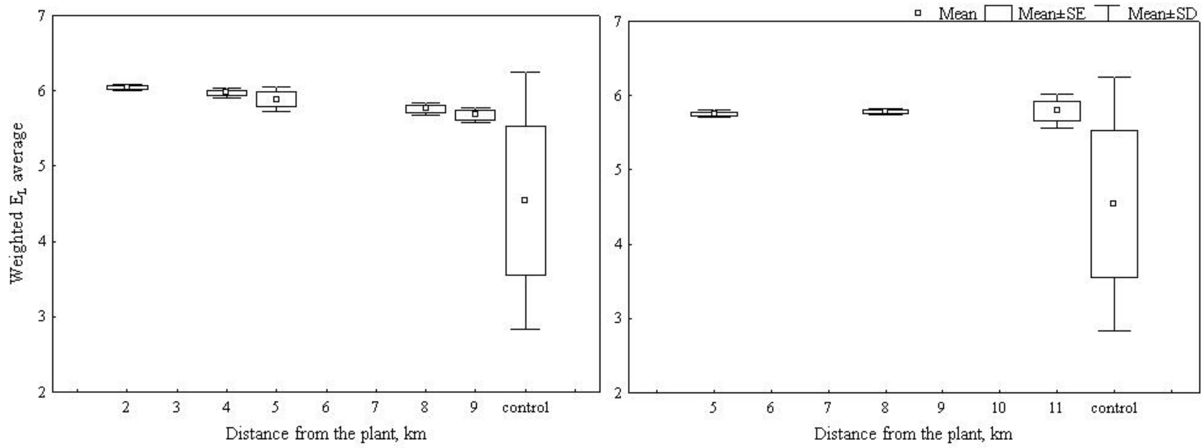

Fig. 3. *Weighted averages for light (E_L) east (A) and north-east (B) from "Achema"*

Table 1. Comparison of indicator values between the sample plots and reference level. Table shows t values of t-tests for unmatched pairs (negative values indicate that the averages for reference level were lower than those for sample plot)

Sample plot	Direction and distance (km) from "Achema"	Light (E_L)		Acidity (E_R)		Nitrogen (E_N)	
		t- value	*p*	*t*- value	*p*	*t*- value	*p*
1	E* – 2	1.52	0.20	-0.75	0,. 9	4.04	**0.01**
2	E – 4	1.45	0.23	-1.19	0.29	3.01	**0.04**
3	E – 5	1.36	0.24	-2.79	**0.04**	3.32	**0.03**
4	E – 8	1.24	0.28	-1.63	0.18	5.90	**0.004**
5	E – 9	1.16	0.31	-0.70	0.50	2.47	0.06
6	NE** – 5	1.23	0.28	-2.65	0.06	7.02	**<0.001**
7	NE - 8	1.26	0.27	-2.55	0.06	11.30	**<0.001**
8	NE – 11	1.26	0.27	2.15	0.09	4.87	**0.008**

** E – east, ** NE – north-east from „Achema“*
Note: values in bold type were statistically significant ($p<0.05$)

The E_R indicator values were lower in the sample plots than those in the reference, e.g. more plant species tolerating lower soil acidity were in the impact zone (Table 1). The differences in E_N were more marked and significant almost in all cases. There was a relatively major part of nitrophilous species downwind of the plant in comparison with the reference (Table 1). This showed outspread of the species demanding more soil nitrogen in the pollution impact zone of "Achema".

Quantification of species along the environmental gradients has for long been a subject of the study regarding natural plant communities and, more recently, ecosystems disturbed by anthropogenic emissions of eutrophying and acidifying substances. The analysis of indicator values showed that the habitats of surroundings of "Achema" vegetation changed, probably greatly, because of increased acidifying and eutrophying pollution. M. Diekman et al. (1999) defined two general relationships in mixed decidous forests in South Sweden: the higher the soil pH, the higher the fertility; and the higher fertility, the higher the canopy closure and the lower the light intensity. According to our study indicator values results it could be concluded that in the surroundings of "Achema" the lower was the soil pH, the higher the fertility; and the higher the fertility, the lower the canopy closure and higher the light intensity. This discrepancy showed the changed ecosystem conditions under the influence of pollution of "Achema". Species indicating a nitrogen rich environment (indicator values for soil nitrogen E_N = 6-8) constituted a more important part of pine forest vegetation under the intense influence of "Achema" and indicated a change in the species composition. Decrease in soil reaction according to indicator values in the impact zone can be explained by the continuance of pollution since 1960s.

4. Conclusions

1. Weighted averages of indicator values for nitrogen (E_N) close to the plant were higher than those in the farther plots and decline with the distance from the emission source. A relative share of nitrogen indicating species was significantly higher in the impact zone (E_N = 2.7) than in the control (E_N = 1.5). The increased abundance of nitrogen indicators in the forest ground vegetation could partly be attributed to an increase in atmospheric nitrogen deposition in the forests.
2. Weighted averages of Ellenberg's indicator values for soil reaction (E_R) along the study transect were not significantly correlated with the distance from "Achema". In the closest to "Achema" vicinity (2 km east and 5-8 km north-east) E_R was significantly lower in comparison to the control ($p < 0.05$). The relative share of acid soil indicating species (R = 2-3) was slightly lower in the impact zone (E_R = 3.0) than in the control (E_R = 3.1), but the difference was not significant ($p > 0.05$).
3. According to the indicator values of light (E_L), there were no significant differences at different distances. In comparison with the control indicator the averages for light were higher but not significant ($p > 0.05$).
4. As the deposition of acidic pollutants, including in particular nitrogen, has increased greatly since the beginning of "Achema" production activities, it is highly probable that the important changes have taken place during the recent decades. According to the indicator values we conclude that in the impact zone (2-11 km) the ground vegetation of pine stands is affected due to "Achema" acidifying and eutrophying pollution.

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Pušynų (*Pinus sylvestris* L.) rūgštėjimas ir eutrofikacija remiantis indikatorine rūšių analize

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Vytauto Didžiojo universitetas

(gauta 2009 m. rugsėjo mėn.; atiduota spaudai 2009 m. rugsėjo mėn.)

Tyrimo tikslas – įvertinti augavietės sąlygų pokyčius AB „Achema“ gamyklos rūgštinančių ir eutrofikuojančių teršalų poveikio zonoje pagal indikatorines poreikio ir tolerancijos aplinkos veiksniams reikšmes. Vertinant gamyklos taršos poveikį augaviečių eutrofizacijos laipsniui, nustatyta, kad nitrofiliškumo reikšmės (E_N) poveikio zonoje buvo statistiškai patikimai didesnės nei sąlygiškai švarios aplinkos augaviečių reikšmės ($p < 0.05$). Vidutinės indikatorinės rūgštumo (E_R) reikšmės buvo statistiškai patikimai mažesnės 5–8 km šiaurės–rytų kryptimi, palyginti su kontrolinėmis vidutinėmis žaliašilio reikšmėmis. Rūgštumo tolerancijos ir poreikio azotui indeksų kaitos tendencijos parodė, kad, tolstant nuo gamyklos, augalų rūšių, toleruojančių rūgščią ir azotu prisotintą dirvą, mažėja.