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MONITORING OF PINE FORESTS UNDER AIR POLLUTION IN THE NORTH-EAST OF THE EUROPEAN PART OF RUSSIA

Nadezhda Torlopova

Institute of Biology, Komi SC UB RAS, 167982, Kommunisticheskaya st., 28, Syktyvkar, Russia. E-mail: torlopova@ib.komisc.ru

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Abstract

The present study aimed to estimate the dynamics of vitality of ground vegetation components under air pollution by pulp and paper industry emissions. The majority of pollutants were oxides of sulfur, nitrogen, sulfur-organic compounds, and alkaline dust. The vitality determination of tree stands was carried out according to ICP-Forests program technique, which is based on ranging trees in classes depending on crowns condition. The studies were conducted in pine forests of *Pinetum fruticulosum* type situated along the pollution gradient. From 1998 to 2009 the share of healthy trees has increased by 1.9 times. Safety and condition of pine undergrowth has deteriorated twice, versus the double increase of the safety of spruce undergrowth has increased by 2 times. Pulp and paper industry air pollution was found to increase leaf discoloration grade and shoot density of dwarf shrubs (*Vaccinium myrtillus* L. and *Vaccinium vitis-idea* L.). For the period of researches, dwarf shrubs essentially improved their condition. Mineralization degree of above-ground parts of dwarf shrubs increased compared to the background area. Species composition of ground vegetation cover significantly changed only in pine forest situated at the shortest distance from the paper plant. Pine stands in the impact area of the pulp and paper mill underwent changes during 1998–2009 which indicated improvement of their condition. Mineralization of snow and discoloration of pine needles had the highest negative relation at far distance from the polluter, versus species composition and projective cover of mosses and epiphytic lichens had the highest direct relation. It is possible to use these parameters as indicators of forest ecological condition.

Key words: pulp and paper plant emissions, tree crown condition, undergrowth, dwarf shrubs condition, chemistry.

Introduction

In a natural environment the vital condition of forest ecosystems depends on the biological features properties of tree species, site habitat conditions and natural abiotic (wild fires, windfalls, and stormbreaks) and biotic (pests and rots diseases) factors. Besides, now forest ecosystems are under a constantly increasing anthropogenic impact, connected with increasing volumes of different types of

cuttings, and increasing air contamination by industrial releases. Therefore, perennial investigations of vegetation dynamics could provide additional information about changes in numerous parameters of forest ecosystems. Assessment of the vital condition of forest ecosystems being under influence of aerotechnogenic emissions of various manufactures should be carried out on the permanent sample plots disposed by emission gradient and in comparison to background areas (Yarmishko 1997).

The purpose of this study was to estimate the vital state dynamics of ground vegetation components exposed to industrial air pollution.

Material and Methods

The largest permanent source of industrial air emissions in the middle taiga zone of Komi Republic is the OJSC "Mondi Syktyvkar" pulp and paper plant (SLPK). The majority of its pollutants are oxides of carbon, nitrogen, sulfur; hydrogen sulfide, sulfur-organic compounds, and mineral dust containing calcium and potassium carbonates and sulfides. Last years, total amount of discharge was about 20 thousand t.year^{-1} that was 1.4 times less than that in 2004 and 1.6 times less than that in 1998 (Ecological report 2008). Investigation area had a mosaic cover and consisted of secondary 60–120-year-old forests after felling and fire. The studies were conducted on eight permanent experimental plots grown by bilberry pine forests, 4 of them being background plots situated 48–52 kilometers northwards from the pollution source and 4 test plots situated 1.3–11.2 kilometers north-eastwards from SLPK in the dominant wind direction (Torlopova and Robakidze 2003). Bilberry pine forests grow on illuvial-humus iron podzolic soils. They are middle-aged, maturing and mature stands formed after felling or fire. These stands are even-aged or relatively even-aged with a mean and relatively high productivity. They consist of pine (*Pinus sylvestris*), aspen (*Populus tremula*), birch (*Betula pubescens, B. pendula*), and seldom Siberian spruce (*Picea obovata*).

Table 1. Increment of pine stand parameters from 1998 to 2009, in %.

Distance from SLPK, km	Height	Diameter	Number of trees	Wood volume
1.3	106	124	79	125
6.5	114	138	59	109
11.0	111	115	86	119
11.2	97	107	66	94
48.5	118	123	83	144
50.0	89	115	87	116
51.0	107	113	94	114
52.0	100	114	84	109

Forest measurements were conducted using by common methods (GOST 1970, Zakharov 1967). Tree crown condition was assessed according to ICP-Forests (Manual... 2006). Qualitative chemical analyses of plant samples were carried out according to certified techniques.

Results and Discussion

For the study period, pine trees in stands on both background and test plots decreased in number (Table 1). However, this decrease in the impact zone was by 50% points higher, and resulted in decreasing the volume increment by a factor of 1.8.

A comparative analysis of vital status of tree stands was conducted (Figure 1). Most informative among other parameters is crown defoliation in comparison to a healthy tree. For example, the share of trees without needle loss in SLPK impact zone compared to 1998 increased by 33-fold. The share of trees with slight defoliation grew by a factor of 3.8. There were no trees with clearly expressed needle loss. These changes pointed out that vital status of the tree stands by crown defoliation improved in 2009 compared to 1998. Discoloration is an important parameter of tree status. This parameter was lowering from 1998 to 2009 but less than defoliation did. The number of trees without yellow needles decreased insignificantly. The share of trees with a low discoloration degree increased 1.4-fold. Trees with a moderate discoloration degree significantly decreased in number (8-fold). Trees without dry branches increased 4-fold in 2009 compared to 1998. The share of 1-class trees (11–25% dry branches) decreased 6-fold; 1% remained for moderately-damaged trees by presence of dry branches. Among all parameters, only tree crown-top condition worsened from 1998 to 2009. The share of trees with a healthy crown-tops

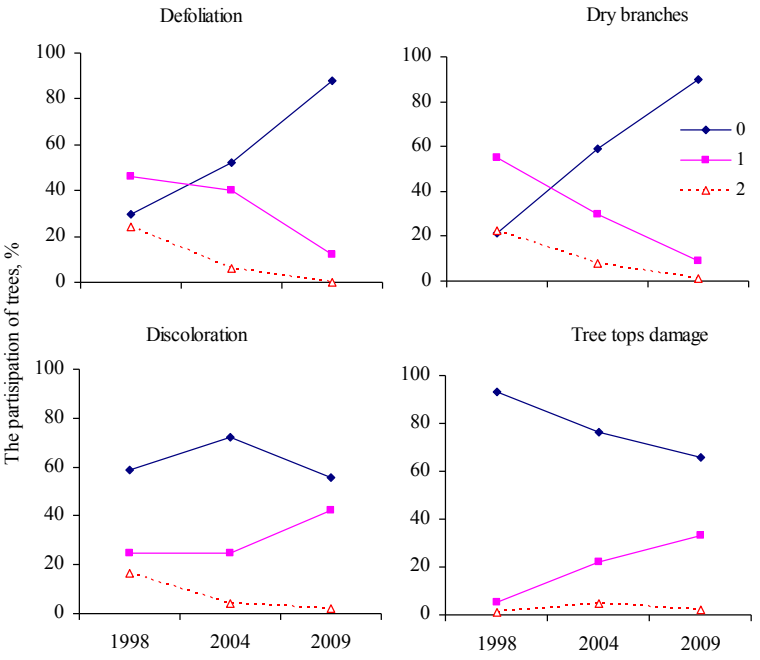

Fig. 1. Parameters of pine crown condition assessment in air pollution impact area.
Tree classes: 0 – undamaged (0–10% of damage), 1 – slightly damaged (11–25% of damage), 2 – moderately damaged (26–60% of damage), tree top damage classes: 0 – healthy, 1 – damaged, 2 – dry.

decreased 1.4-fold; 35% of the trees had damaged crown-tops which was 6 times higher compared to 1998. Tree crown-tops damage may be caused by high concentrations of pollutants in the air due to single emergency discharges.

Each tree was given a damage class accounting for defoliation, discoloration, presence of dry branches in crown and condition of tree top. The closest (1.3 km) to SLPK plot had the highest amount of slightly-damaged trees (25%) among all studied sites. Thus the share of healthy trees fell to 70% there being the lowest value in 2009. Tree stands structure by damage classes on the other plots did not correlate with distance to pollution source and did not show any significant differences between plots.

Analyzing the distribution of trees to damage classes for the observation period led to the conclusion that condition of pine forests in the SLPK impact zone improved for the last 10 years (Figure 2). The amount of healthy trees incresed 1.9-fold. The share of the slightly damaged trees lowered by 3.2-fold, moderately-damaged by 3.0-fold, and severely-damaged by 1.8-fold. In contrast to situation in 1998, the year in 2009 a reduction between the quantities of differently-damaged trees on background and impact plots was observed, whereas the distribution of trees to damage classes remained almost the same in background and test plots.

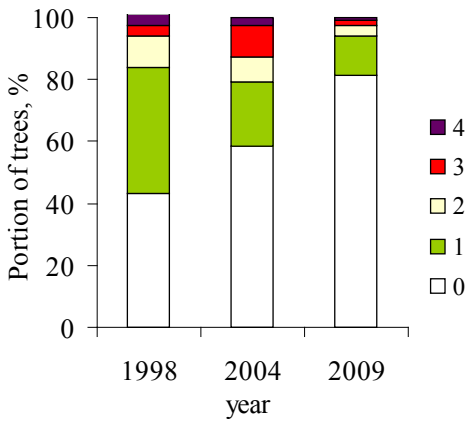

Fig. 2. Trees distribution in the air pollution impact area to damage classes: 0 – undamaged, 1 – slightly damaged, 2 – moderately damaged, 3 – severely damaged, 4 – died.

To estimate the vital state of the tree stands, the index of stand disturbance was calculated using the formula for determining the weighted-mean class of damage to the trees comprising the stand. According to Alekseev (1997) the index under 0.5 characterizes a stand as a healthy one. In the background areas, the index decreased by 1.3-fold compared to that in 1998 and by 1.2-fold compared to that in 2004 (Figure 3). The damage index in the impact zone decreased 3.1 and 2.8-fold, respectively. This happened because of the reduction of the share of trees of all damage classes tree portion (in 2004 slightly- and moderately-damaged and in 2009 moderately- and severely-damaged trees) and because died standing trees had fallen down on the ground. A comparative analysis of the damage index of woods on polluted plots in 1998, 2004, and 2009 showed an essential improvement of pine forests vital status. All studied tree stands within the SLPK impact zone were characterized as healthy in 2009.

For growth intensity comparison of tree stands the method of an evaluation of their average diameter at the age of 60 years (minimum age among the in-

vestigated pine forests) was approved. Reducing the diameters of uneven-aged pine forests to 60-aged stand has allowed us to make a correct comparative analysis of their growth. Secondary pine forests from polluted area had the least value average diameter of 60-year-old trees relative to other secondary and primary pine forests. For assessment of annual loss of wood volumes in secondary pine forests because of releases influence of pulp-and-paper mill a comparison between the mean annual single tree wood increment and that in pine stands formed after clear-cutting was carried out. It was shown that the mean annual single tree wood increment of one tree from polluted area in true moss pine forests was less than 1.6 dm^3 compared to other secondary pine forests. Taking into account the average number of trees in pine forests from polluted area (1200 trees per ha) it was calculated that the annual loss of wood reaches up to 1.9 $m^3.ha^{-1}$ per year.

Ground vegetation layer was studied by the method of registration plots 50 x 0.5 m x 0.5 m. These plots had been established regularly through forest sample plot. Ground cover of each species, and shoots number of *Vaccinium* on each plot were registered.

Undergrowth was dominated by healthy spruce trees. Pine and birch in undergrowth dies at different development stages (Table 2). Compared to 1998, the amount of healthy spruce undergrowth increased 2-fold (Figure 4).

In pine forests, individuals of *Vaccinium myrtillus* L. per area unit increased in number logarithmically closer to pollution source ($r^2 = 0.76$). Intensive appearance of new shoots is possible only on condition that other vascular plants less

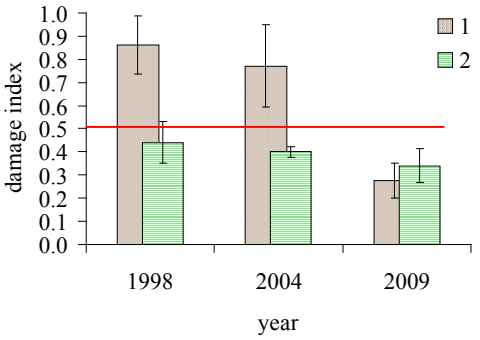

Fig. 3. Damage dynamics of pine stands under air pollution (1) and background (2). Index: healthy stand <0.5< slightly damaged stand < 1.0 < moderately damaged stand.

resistant to toxicants decrease in number which was proven in pine forests under heavy metal pollution. In 1999 polluted pine forests showed an increase in densities of *V. myrtillus* – 2.1-fold and, in density of *V. vitis-idaea* L. – 1.3-fold compared to background. In 2007 the differences between background and test areas decreased to 1.3 for *V. myrtillus* and to 1.1 for *V. vitis-idaea*, respectively. The investigation of the assimilation ap-

Table 2. Distribution of undergrowth species in pine forests in air pollution (above the line) and background (below the line) areas, individuals per ha.

Species	1999	2004	2009
Spruce	231 / 900	739 / 1061	347 / 950
Pine	280 / 210	119 / 0	44 / 33
Birch	– * / –	668 / 307	256 / 683

* in 1999 birch not detected.

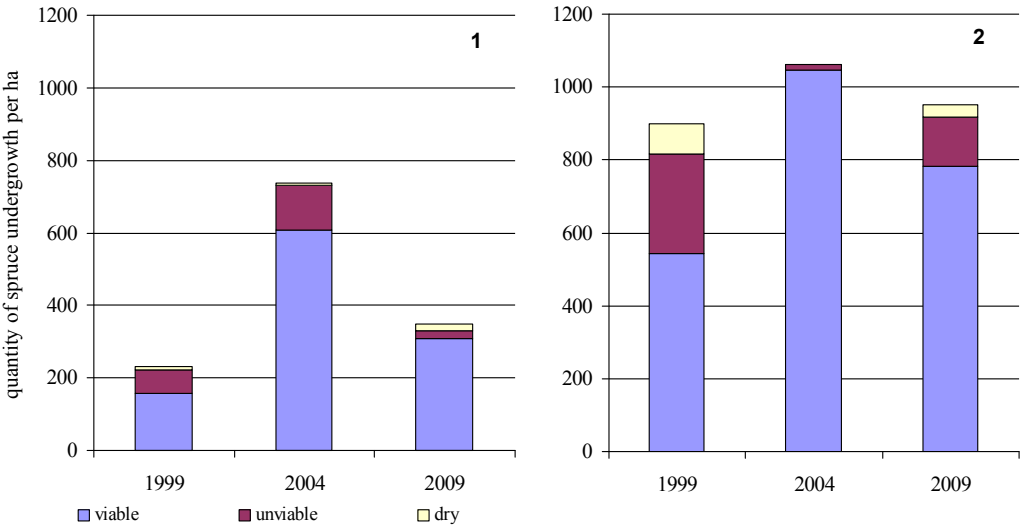

Fig. 4. Distribution of spruce undergrowth by viability in air pollution (1) and background (2) areas.

paratus of the dominating plants in the herb-undershrub layer showed a high damage grade of leaves within SLPK impact zone. Leaves were found to be yellow and brown in color, with dotty burns, and even decomposition of tissues was observed. In 1999 the share of damaged *V. myrtillus* individuals in pine forest in the impact areas was about 2.5 times higher compared to the background area while the share of damaged *V. vitis-idaea* 4.4 times. In 2007 the values for both species in the background areas remained unchanged while those in the test areas were only 1.5 time higher for *V. myrtillus* or remained the same as background for *V. vitis-idaea*.

Pulp and paper industry air pollution was found to increase leaf discoloration grade and shoot density of dwarf shrubs (*V. myrtillus* and *V. vitis-idea*). For the period 1999–2007, dwarf shrubs essentially improved their condition. Population density of dwarf shrubs did not reliably change. Mineralization degree of above-ground parts of dwarf shrubs increased compared to the background area. Species composition of the ground vegetation cover significantly changed only in pine forest situated at the shortest distance to the paper plant.

One of the principal factors which defines normal growth and development of plant is optimal supply with nutrients. Soil and atmosphere are the main source of nutrients. Air pollution is known to increase mineral elements quantity in assimilatory organs. Ash content (excluding N) of pine needles in both pollution impact zone and background area was 1.2–1.5% of dry weight. Nutrient status of pine needles was potassium-nitrogenous. In polluted area the contents of K, Ca, P, Mg and Mn in needles were lower, while the content of Al and Na was higher, compared to the background (Figure 5). Nutrient status of undershrubs leaves was distinguished by prevalence of Ca over K. Ash content of

undershrubs leaves was higher, than that of pine needles. In polluted area an increase of undershrubs leave ash content was detected. The contents of C, N, and S total contents in assimilatory organs of pine as well as of dwarf shrubs were very invariable. Nitrogen and carbon shares prevailed in needles, and sulfur prevailed in *V. vitis-idaea* aboveground organs. Inverse correlation between the contents of the main nutrient elements (Ca, P, and Mg) and Fe and discoloration of *V. myrtillus* leaves was found.

Conclusion

Monitoring of bilberry pine forests under SLPK aerotechnogenic pollution started in 1998 and has shown a dynamically changing vital status of tree stands. In contrast to 1998, only 12% of pine trees had signs of needles loss in the impact zone in 2009. However, the slight discoloration of needles remained unchanged with increasing share of crown-top damaged trees. A stable increasing proportion of healthy trees in composition was found with a simultaneous reduction in the proportion of slightly- and severely-damaged trees. Aerotechnogenic pollution was harmful to ground cover plants, it reduced specific diversity of grasses, mosses and increased leaf damage of undershrubs. Grassy plants were replaced by undershrubs which lead to an increasing density of *Vaccinium myrtillus* and *V. vitis-idaea*. For the period 1999–2007, undershrubs improved their status. For the study period, both test and background plots were found for reducing ash value in needles. As in 1998, and in 2009, none of the pollutants such as carbon compounds, sulfur and nitrogen oxides do not accumulate any in pine needles (excluding 1.3-km-distance impact plot) or leaves of Vaccinium myrtillus and V. vitis-idaea, and in forest litter. Due to discharged mineral dust and solid particles, leaves of *V. myrtillus* and forest litter accumulated calcium, magnesium, potassium, manganese, and sodium, but not in pine needles. For the period 1998–2009 by applying integral damage index analysis, the vital status of bilberry pine forests in polluted plots improved by a factor of 3. As summarized by Emberson et al. (2003) sub-critical concentrations of pollutants (sulfur and nitrogen oxides, such as well as suspended particulate matter) can produce a fertilizer effect on plants, especially

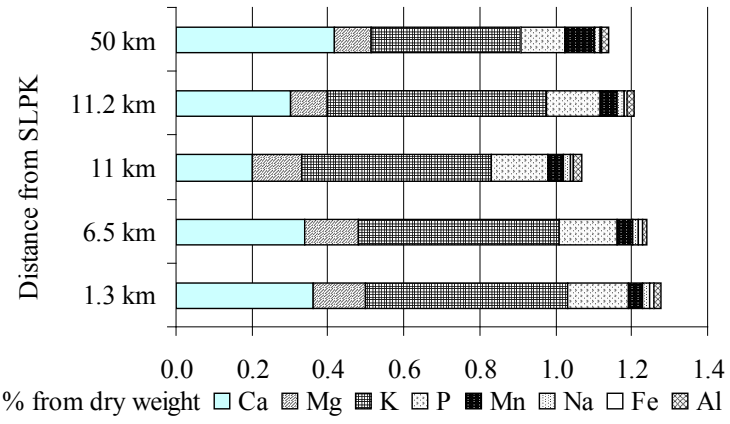

Fig. 5. Mineral composition of 2-year-old pine needles in 2009.

on those growing in poor nutrient condition, for example in the European North. Mineralization of snow and discoloration of pine needles have the highest inverse relationship with distance from the polluter, versus species composition and projective cover of mosses and epiphytic lichens have the highest direct correlation. It is possible to use these parameters as indicators of an ecological conditions. The results of the present study could be used in forest management modeling and forecasting.

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