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ALTERATION IN VITAL STATE PARAMETERS OF SCOTS PINE TREE-STANDS UNDER TECHNOGENIC POLLUTION

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Abstract

The study was focused on the relation between deterioration of vital state parameters of Scots pine (*Pinus sylvestris* L.) tree-stands polluted by various technogenic sources, and the level of polluting agents accumulation in the needles. Changes in the balance of the most important biogenic elements and their proportion in the needles of polluted trees have been shown. The results confirm systemic character of polluting agents impact on tree-stands vital state. It may be presumed to show in the following order: polluting agents accumulation in assimilating organs → disbalance of elements composition of plant organism → disturbance of plant organism nutritious conditions → disturbance of tree growth characteristics → reduction of tree-stands productivity.

Key Words: air pollution, *Pinus sylvestris* L., vital parameters, East Siberia.

Introduction

Technogenic load is currently considered to be one of the most powerful factors destabilizing forest ecosystems of boreal zone (Smith, 1985; Forest ecosystems…, 1990; Isayev, Korovin, 1998; Plant Responses…, 2004). The enhancing pressure of this negative factor results in decrease of medium-forming, medium-restoring and production potential of forests, particularly coniferous ones; this makes especially topical the studies, which allow to reliably diagnose changes in the state of this biospheric component.

Specific character of the impact of technogenic chemical pollution shows in disturbance of biochemical cycles of many elements in biogeocenoses at the expense of unregulated introduction of substance with the waste. A new – technogenic – type of chemical elements migration has appeared; its scope, speed and intensity exceeds natural emergence of these elements (Nikonov et al., 2004). On the affected territories polluting agents usually act as dominant factors determining the state of ecosystems (Mikhailova et al., 2006). Technogenic emissions may result in the most catastrophic consequences – up to complete destruction of biocenoses (Kharuk et al., 1996; Yarmishko, 1997; Mikhailova, 2000).

The current situation requires justification and regulation of optimal proportions between natural and technogenic flows of elements in forest ecosystems of boreal zone and determination of critical chemical loads. To achieve this it is necessary, first, to investigate basic elements pools (in background territories) and their changes under chemical pollution (in the affected territories) and secondly, to study response to pollution of ecosystems components, that is disturbance of characteristics of their state. As it is tree-stand that assumes major technogenic load determining all the further circulation of elements in the forest ecosystem (Vorobeichik et al., 1994), the study of changes in the parameters of its state becomes the primary objective.

The present work was aimed to investigate the relation between changes in the parameters of vital state of technogenically polluted tree-stands of Scots pine (*Pinus sylvestris* L.) and the level of accumulation of polluting agents in its needles.

Material and methods

We chose Scots pine (*Pinus sylvestris* L.) as an object of research based on the results of many years of studies of boreal forest ecosystems. It has been shown that this species, besides wide distribution and important forest-forming functions, is characterized by high sensitivity to technogenic polluting agents (Mikhailova, 2000). High correlation degree has been established between levels of sulfur dioxide, hydrogen fluoride, heavy metals aerosols in the polluted atmospheric air and accumulation in pine needles of respective elements – sulfur, fluorine, lead, cadmium, mercury, etc. (Mikhailova et al., 2003).

Scientific research has been conducted in Eastern Siberia (Irkutsk region) in the background territories and zones polluted by technogenic emissions of three different industrial centers (pollution sources) (Fig. 1). The emissions of the first pollution source (source N 1) are dominated by lead aerosols, the emissions of the second source (N 2) contain significant amounts of fluorides, those of the third source (N 3) include a lot of sulfur-containing polluting agents (mainly sulfur oxides).

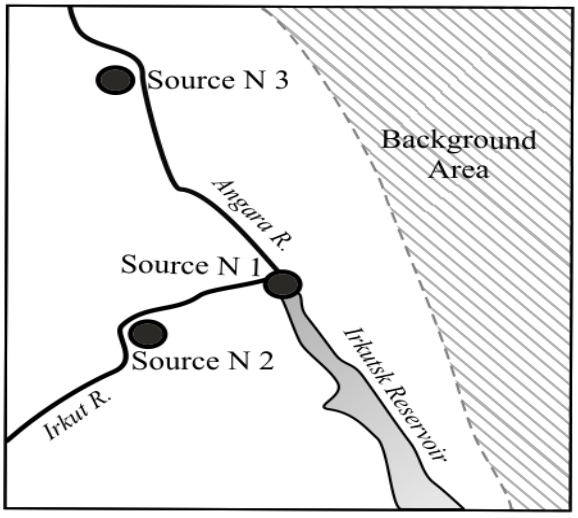

Fig. 1. Location of pollution sources in the territory under study

Forest ecosystems were investigated on experimental plots, which were set taking into account geographic position of pollution sources, regional wind mode, specificity of local air masses circulation, peculiarities of relief and hydro-grid. At each experimental plot pine needle samples were collected for further analysis of pollution agents content.

Detailed study of tree-stands was conducted in accordance with the standard methods (Manual…, 1994; Methods…, 2002). At each experimental plot 5-6 pine trees of the second age class were selected to collect needles samples and determine a number of other parameters. The content of the following elements was determined in laboratory conditions: sulfur, fluorine, aluminum, arsenic, lead, cadmium, mercury, nickel, lithium, barium, zinc, iron, vanadium, molybdenum. Background (control) samples of pine needles were collected at the distance 100-250 km away from industrial centers along the directions outside the main emissions transfer.

Elements chemical composition in plant samples was determined by generally accepted methods of atomic adsorption spectrophotometry, flame photometry, photocolorimetry (Proydakova et al., 1986; Methods.., 1987). At the same time at each

experimental plot parameters of pine tree-stands vital status were determined: crown defoliation level, stem volume and height, shoots length, needles age, needles mass on the shoots, length and mass of one needle, the number of needles pairs on the shoots. Measurements were conducted with 30-100 repetitions. Statistical processing of the data obtained was performed with software «Statistical computing environment R».

Results and discussion

A significant amount of polluting elements was found to accumulate in tree needles on experimental plots polluted by various technogenic sources. The content of the elements measured is found to exceed the background level by 1.5 – 13.5 times (Table 1). There is a correlation between the content of dominant polluting agent in the emissions and pine needles. Thus, near pollution source N 1 tree needles demonstrate much higher accumulation of lead, near pollution source N 2 – fluorine, N 3 – sulfur. Fairly high levels of iron, vanadium, lithium, molybdenum are found in the needles of trees polluted by source N 1, those of lead, barium, arsenic, lithium – at the experimental plots near pollution source N 2, nickel, molybdenum, iron – near N 3.

Table 1. Surpass of background concentrations (times) of elements in the needles of trees polluted by different sources of technogenic emissions

Polluting element	Sources of technogenic emissions		
	N 1 (lead aerosols prevail)	N 2 (high fluorides level)	N 3 (sulfur oxides prevail)
Sulfur	3.4	3.3	4.1
Fluorine	2.3	8.0	1.5
Lead	10.1	4.5	7.2
Arsenic	3.7	4.5	2.6
Mercury	2.3	1.7	1.9
Aluminum	3.5	2.5	2.0
Iron	7.1	2.5	4.5
Zinc	2.0	2.0	2.0
Barium	4.0	4.4	2.4
Nickel	2.3	3.5	13.5
Lithium	6.1	9.0	4.6
Vanadium	8.0	2.7	3.8
Molybdenum	9.0	2.5	11.0
Cadmium	3.3	3.4	1.5

Accumulation of polluting elements changes the balance of most important biogenic elements in needles and their proportions, which indicates disturbance of plant organisms

nutrient status and shows in oppression of growth processes and reduction of the amount of trees assimilating phytomass (Mikhailova et al., 2006; Michael, 2014). Thus, according to the data acquired, in pine needles of the background territories the proportion N:P:K virtually coincides with the optimal one (Pobedov et al., 1977), while in the needles of polluted trees it changes at the expense on increase of nitrogen level and decrease of potassium level, with phosphorus only weakly participating (Table 2). The most intense change in this proportion is found in the needles of the trees polluted by fluorine-containing emissions (source N 2). The proportion N:K and N:P shows a well pronounced increase of nitrogen share along with simultaneous reduction of potassium and phosphorus levels. Potassium level decreases in the proportions with calcium and magnesium.

Table 2. Proportions* of concentrations of biogenic elements in the needles of pine trees polluted by various sources

Proportions of elements	Pollution sources			Background territories
	N 1	N 2	N 3	
N:P:K	76:9:16	78:7:15	75:8:17	69:10:21
N:K	83:17	84:15	81:19	77:23
N:P	90:10	92:8	91:9	88:12
K:Ca	32:69	31:69	35:66	43:57
K:Mg	65:35	64:36	68:33	74:26

*Proportions were calculated as a percentage of each element from the sum of concentrations of two (three) elements compared in needles dry mass.

Analysis of vital state parameters of tree-stands at the same experimental plots demonstrated their considerable change as compared to background indices. The following parameters changed to a particularly significant extent: crown defoliation level, needles mass on the shoots of the 2-nd year, stem volume, number of needles pairs on shoots, shoot length (Table 3).

Table 3. Parameters ($\bar{x} \pm S_{\bar{x}}$) of vital state of tree-stands in background territories and on experimental plots polluted by various sources

Parameters	Pollution sources			Background territories
	N 1	N 2	N 3	
Defoliation level, %	60.0±5.0	55.0±5.0	60.0±5.0	25.0±5.0
Needles mass on the shoots of the 2-nd year, g	4.73±0.41	5.43±0.62	4.68±0.46	12.45±2.45

Stem volume, m^3	0.30±0.04	0.43±0.05	0.22±0.03	0.85±0.11
Number of needles pairs on shoots, units	53.10±11.94	71.08±19.78	47.44±12.63	152.80±24.08
Shoot length, cm	7.44±3.15	9.77±3.95	7.82±2.85	18.31±3.75

These parameters are characterized by similar trend of changes, which depends on the level of polluting agents accumulation expressed in nonlinear change of their values with the increase of polluting elements content in needles – defoliation level increases sharply with other parameters significantly decreasing. A particularly close correlation is found between the enumerated parameters of tree-stands vital state and accumulation of sulfur, fluorine, lead, mercury in the needles; this is evidenced by estimated high correlation coefficients (r = 0.95 – 0.65, P = 0.05, n = 35).

As deterioration of tree-stands vital state parameters in territories polluted by various sources follows a similar trend described by non-linear function, the identified regularities provide basis for mathematical calculation of threshold concentrations of polluting elements in pine needles. We have calculated such concentrations for priority polluting agents (Table 4). These concentrations (content) of polluting elements corresponds to latent (hidden) phase of tree-stands weakening, which does not manifest changes in morphostructural parameters of their vital state. Surpassing these threshold concentrations may result in the development of tree-stands degradation.

Table 4. Threshold and background content ($\bar{x} \pm S_{\bar{x}}$) of polluting elements in Scots pine needles in Eastern Siberia (Irkutsk region)

Element	Element content, % dry needle mass	
	threshold	background
S ($\times 10^{-2}$)	3.63±0.40	2.90±0.12
F ($\times 10^{-3}$)	1.31±0.17	1.01±0.05
Pb ($\times 10^{-5}$)	1.75±0.33	1.70±0.17
Hg ($\times 10^{-6}$)	0.92±0.17	0.69±0.22

The results of the study conducted provide evidence of systemic influence of polluting agents on tree-stands vital state. It may be presumed to show in the following order: polluting agents accumulation in assimilating organs → disbalance of elements composition of plant organism → disturbance of plant organism nutritious conditions → disturbance of tree growth characteristics → reduction of tree-stands productivity. The data provided by other authors confirm systemic character of the impact of atmospheric polluting agents on nutrient status of arboreal plants (Innes, 1993; Nikolayevsky, 1998; Yarmishko et al., 2003;

Nakatani et al., 2004). Moreover, studies of this aspect contribute to establishing cause-and-effect links between active negative factor, in this case – technogenic pollution, and oppression of tree-stands vital state resulting in disturbance of their main medium-forming functions. This justifies adequacy of applying such approach to diagnostics of vital state of tree-stands subjected to the impact of atmospheric industrial emissions. In practice, such studies are important not only for evaluation of tree-stands state on polluted territories, but for justifying the limits of acceptable technogenic exhaust in boreal forests.

Conclusion

The investigation of Scots pine tree-stands in the territories polluted by various sources demonstrated accumulation in the needles of significant amounts of polluting elements. Their content was found to exceed the background level by 1.5 - 13.5 times. Accumulation of polluting elements changes the balance of important biogenic elements in needles and their proportions, which proves disturbance of nutrient status of plant organism. Polluted tree-stands are characterized by deterioration of vital state parameters – significant increase of crown defoliation level, stem volume reduction, mass decrease in needles on the shoots, the amount of needles pairs and length of the shoots. The impact of polluting agents on tree-stands vital state is concluded to be of systemic character.

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