Influence of Anthropogenic Load in Plant Communities with Pinus sylvestris L. In the West Siberian Subarctic Region

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Abstract. The paper presents the results of comprehensive studies of anthropogenic roadside phytocenoses of the West Siberian Subarctic Region in Russia. For the study, 3 land plots with different anthropogenic load were selected. The atmosphere clearness was determined using the needles of Pinus sylvestris L. as indicator (intact, with spots, with chlorosis, with necrosis). The index of flora synanthropization was determined, which is in the range of 50 to 64%. When studying the anthropogenic load, the accumulation of heavy metals (Zn, Cu, Fe, Cd, Pb, Cr, Ni) in the needles of Pinus sylvestris L. was determined. As a result of anthropogenic impact, there is a change in the composition of chlorophyll, as well as carotenoids. However, chlorophyll a and b decrease, and the number of carotenoids increases. Thus, there is a certain protective reaction of the plant organism to the effects of heavy metals. All these features are specific for Pinus sylvestris L. and in the aggregate give a true picture characterizing the state of the environment.

Keywords: West Siberian Subarctic Region · Pinus sylvestris L. · Heavy metals · Carotenoids · Chlorophyll · Roadside phytocenoses

1 Introduction

The implementation of the basic principles of sustainable development of civilization in modern conditions is feasible only with the availability of appropriate information on the state of the habitat in response to the anthropogenic impact collected during biological monitoring. For rational nature management and research in the field of ecology, it is necessary to correctly determine and conduct monitoring studies of the quality of the natural environment [1, 2].

The reclamation and disturbance of forest ecosystems in the suburban forests of large industrial cities are significant factors, therefore, the need for a complex of environmental protection measures aimed at preserving the biodiversity of ecosystems and their performance of habitat forming and environmental protection functions is obvious.

Pine forests are very sensitive to anthropogenic impact. Of particular importance here is air pollution. In this paper, the choice of Scotch pine for determining the impact

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of pollutants is substantiated. In many studies, Pinus sylvestris L. is an environmental indicator [3, 4].

Bioindication is one of the most accessible ways of assessing the air condition in a location. Pinus sylvestris L. was chosen as a bioindicator, since this tree species is one of the most sensitive to long-term air pollution and the most widespread one in the studied area.

Pinus sylvestris L. belongs to arboreal gymnosperms evergreens. The plant differs in the structure of the leaves: the needle leaves live for up to five years and fall off annually only partially, so the tree seems evergreen. The wood of the plants fills almost the entire mass of the trunk, the core is poorly developed and the bark is very thin [5, 6].

Almost all emissions negatively affect the plant. Plants age early, their crown gets thin and disfigured, the needles turn yellow and fall off prematurely. For example, under normal conditions, pine needles fall off after 3–4 years, near atmospheric pollutants, damage occurs faster. Under the influence of toxicants, the needles of Scotch pine can change color, become brown, then dry out and fall off. Periodic exposure to nitrogen and sulfur oxides causes pine needles to fall off, which persists only on the shoots of the last year [7].

Morphological and anatomical changes, as well as the lifespan of needles, are informative in terms of the technogenic air pollution. With chronic pollution of forests, damage and premature fall of needles are observed. In the zone of technogenic pollution, there is a decrease in the mass of needles [8].

The photosynthetic apparatus is very sensitive to various anthropogenic influences. Therefore, it is very important to study the effect of pollutants (heavy metals) on bioindicators. Many researchers are currently conducting observations in the field of photosynthesis and various aspects of its regulation. Scientific interest is the study of the environment with the help of растений-bioindicators [9].

In order for the process of photosynthesis to function normally, certain conditions are needed, especially external ones. Chlorophyll a and b play a huge role in the process of photosynthesis. However, there are fat-soluble pigments of an aliphatic structure, they have a yellow and orange color, they are called carotenoids, which are sensitive to changes in the environment. [10].

Heavy metals enter the natural environment in various ways, through the soil, atmospheric air. In this work, studies were carried out on roads as sources of anthropogenic pollutants entering plant communities. The accumulation of heavy metals in plant ecosystems of the West Siberian Subarctic was studied.

2 Material and Methods

Geobotanical description was carried out at the time of the study according to generally accepted methods. The plots were selected with a size of 16m^2.

The abundance was determined according to the Drude scale: soc (socialis); cop3; cop2; cop1; sp; sol; un.

Changes in flora and introduction of species were also determined. For this, the synanthopization index was calculated. [11, 12].

Assessment of the degree of synanthropization was carried out according to the method of R.I. Burda. The percentage is calculated by the formula (1):

$$\mathrm{X} = \mathrm{S_{sp}}/\mathrm{S_t} \times 100\% \tag{1}$$

where $\mathrm{S_{sp}}$ – the number of synanthropic species $\mathrm{S_t}$ – the total number of species on the site.

The degree of damage to the needles was revealed. For the study, 200 needles were selected from 10 trees in three test land plots (LP) and, in accordance with the methodology, the ratio of damaged and healthy needles was calculated. All needles were carefully examined to determine the class of damage and drying out.

In order to determine pigment content, the spectrophotometric method was used [14, 15].

The concentration of chlorophyll a, b (2, 3) and carotenoids (4) was calculated with the Wintermans and De Mots equation for ethanol (2, 3, 4):

$$C_a = 13.70 \times E_{665} - 5.76 \times E_{649} \tag{2}$$

$$C_b = 25.80 \times E_{649} - 7.60 \times E_{665} \tag{3}$$

$$C_k = 4.7 \times E_{440} - 0.27 \times C_{(a+b)} \tag{4}$$

Scotch pine needle samples were placed in a speedwave MWS-2 system manufactured by PerkinElmer (USA) microwave digestion system.

To determine the accumulation of heavy metals in needles, the inductively coupled plasma method was used on an atomic emission spectrometer Optima 7000 DV manufactured by PerkinElmer (USA).

3 Results

As a result of the study of the Subarctic region within Western Siberia, some key areas were explored:

Land plot 1. The western side of the Surgut – Kogalym highway, about 20 km north of the Surgut – Kogalym / Surgut – Nizhnevartovsk highway intersection. Surgut province. The coordinates of the Land plot are N 580 09′084″, E 680 45′013″. The dominant tree species is Pinus sylvestris L. with a height of 23–25 m. There are quite a lot of Pinus sibirica Du Tour in the plot, as well as Betula pendula Roth reaching the same height. The dense undergrowth of Abies sibirica Ledeb is very well developed. The forest stand formula is as follows: 6Psyl2C2B + Ab.

The undergrowth is well developed, it is made up of low-rise trees – Padus avium Mill. And Sorbus aucuparia L., as well as shrubs – Rosa acicularis Lindl., Ribes hispidulum (Jancz.) Pojark.), as well as individual plants of Salix caprea L.

In the grass-subshrub layer, the main dominant is Carex macroura Meinsh (cop3). Present in high abundance are also Aegopodium podagraria L. (sp.), Dryopteris carthusiana (Vill.) H.P. Fuchs (sol.), Lathyrus vernus (L.) Bernh. (sp.), Vicia sepium L. (sp.), Oxalis acetosella L. (sol.). These species form the general taiga appearance to this portion of the forest. Sparse individuals of Lilium pilosiu sculum (Freyn) Miscz. (un.), a rare plant with decorative qualities, are interspersed in the area's vegetation.

The condition of all plants is satisfactory. Species protected in the Tyumen Oblast, as well as endemic species, were not found within the area of the study.

Land plot 2. The area of the border of the northern taiga and forest-tundra, the border of the South Nadym-Pur and Pur-Taz provinces. Along the Korotchaevo – Purpe highway, 40 km south of Korotchaevo.

The coordinates of the Land plot are N 580 22′839″, E 680 46′345″. The dominant tree species is Pinus sylvestris L. with a height of 33–35 m. There are quite a lot of Betula pendula Roth reaching the same height. The dense undergrowth of Abies sibirica Ledeb is very well developed. The forest stand formula is as follows: 6Psyl4B + Ab.

The undergrowth is well developed, it is made up of low-rise trees – Padus avium Mill. and Sorbus aucuparia L., as well as shrubs – Ribes hispidulum (Jancz.) Pojark.), Rubus idaeus L. is found sparsely.

In the grass-subshrub layer, the main dominant is Carex macroura Meinsh. (cop3). Present in high abundance are also Aegopodium podagraria L. (sol.), Lathyrus vernus (L.) Bernh. (sol.), Fragaria vesca L., (sol.) Luzula pilosa (L.) Willd., Moneses uniflora (L.) A. Gray (sp.), Geranium sylvaticum L. (cop1), Orthilia secunda (L.) (sp.), Ranunculus auricomus L. (cop1), Rubus saxatilis L. (sp.). The condition of all plants is satisfactory. Species protected in the Tyumen Oblast, as well as endemic species, were not found within the area of the study.

Land plot 3. Near the Nadym – Novy Urengoy highway, 21 km east of the village of Stary Nadym. The coordinates of the Land plot are N 583 35′253″, E 685 08′845″. The dominant tree species is Pinus sylvestris L. with a height of 29–30 m. There are quite a lot of Betula pendula Roth reaching the same height. The dense undergrowth of Abies sibirica Ledeb is very well developed. The forest stand formula is as follows: 7Psyl3B + Ab.

The undergrowth is well developed, it is made up of low-rise trees – Padus avium Mill. and Sorbus aucuparia L., as well as shrubs – Rubus idaeus L., Rosa acicularis Lindl., Ribes hispidulum (Jancz.) Pojark.); Viburnum opulus L. and Paris quadrifolia L. are found sparsely.

In the grass-subshrub layer, the main dominant is Carex macroura Meinsh (cop3). Present in high abundance are also Lathyrus vernus (L.) Bernh. (sp.), Vicia sepium L. (sp.), Calamagrostis arundinacea (L.) Roth (sol.), Viburnum opulus L. (sp.), Calamagrostis arundinacea (L.) Roth. (sol.), Filipendula ulmaria (L.) Maxim. (sol.), Maianthemum bifolium (L.) F.W. Schmidt (un.), Pulmonaria mollis Wulfen ex Hornem (un.), Stellaria holostea L. (sp.), Thalictrum minus L. (sp.).

To determine and confirm anthropogenic pressure, the index of flora synanthropization was revealed, which is in the range of 50 to 64%. It can be concluded that synanthropes inhabit the majority of percent on the site. The level of synanthropization (5 points).

The indication of the purity of the atmospheric air was determined by the needles of Pinus sylvestris L. The needles are arranged in two in a bunch, gray or bluish-green, as a rule, slightly curved, the edges are finely toothed. The upper side of the needles is convex, the lower side is grooved, dense, with clearly visible bluish-white stomatal lines. In young trees, the needles are longer (5–9 cm), in old trees they are shorter (2.5–5 cm).

Investigations of Pinus sylvestris L. by damage classes revealed that in the first plot the largest part is needles without spots (68.3%), with 45.6% in the second plot and 40.9% in the third plot. The largest part is needles with small yellow spots, and the smallest part is needles with complete drying out. Needles with small yellow spots account for the following percentage values: 1 (25.3%), 2 (35.9%), 3 (45.2%). All these features are specific for Pinus sylvestris L. and in the aggregate give a true picture characterizing the state of the environment.

In the studied areas, the bulk of the needles is healthy, has no damage, and only a small part of the needles is diseased. In a polluted atmosphere, damage appears, and the lifespan of pine needles decreases.

Selected samples of needles were used to determine the severity of chlorosis and necrosis. Chlorosis is a yellowing in areas where there is either destruction or insufficient formation of chlorophyll in the cells of the photosynthetic tissue of the leaf. Necroses are areas of needles with dead areas of the leaf mesophyll. In addition, the severity of defoliation on the shoots was determined. All these characteristics give a true picture of the state of plants in the studied areas. Thus, after analyzing the data obtained in the investigated land plots, it can be concluded that the degree of atmospheric air pollution is significant. This is evidenced by indicators of the severity of chlorosis and necrosis and the degree of defoliation.

According to the data obtained, we can conclude that the minimum percentage of needles with chlorosis and necrosis was recorded in the test plots: the first plot (needles with chlorosis account for 16.0%, needles with necrosis – 10.0%); the second plot (needles with chlorosis – 18.0%, needles with necrosis – 10.5%); the third plot (needles with chlorosis account for 10.0%, needles with necrosis – 3.9%). The largest percentage of needles with chlorosis and necrosis was recorded in the urban environment.

It was found that under anthropogenic load, needles with drying out predominate over intact ones. In an area with a high content of gas and dust, the number of needles with spots is almost twice as large as in a clean area. This indicates that the polluted air contains twice as many hazardous substances, which are retained by the leaf surface of the pine, leading to the formation of spots with subsequent drying out.

To study the anthropogenic load, the accumulation of heavy metals in plant objects was investigated, their accumulation in the needles of Pinus sylvestris L. was determined. Zn 46.88–65.30; Cu 5.10–8.12; Fe 76.50–145.22; Cd 0.11–0.23; Pb 0.42–0.65; Cr 0.88–1.58; Ni 3.72–6.78 mg/kg, the results are reliable at $P < 0.05$ (Table 1).

It is noted that the greatest amount of heavy metals is accumulated in needles of the pines found in the third plot. Based on the increase of the anthropogenic load, the plots were lined up in the following order: $3 > 2 > 1$.

As a result of research, the photosynthesis system reacts to anthropogenic pollution. As a result, it was found that under the influence of pollutants there is a decrease in chlorophyll a in the studied areas 3–1 (1.90–3.23) mg/g. The accumulation of heavy metals caused a decrease in chlorophyll in the needles.

Table 1. Heavy metal content in pine needles, mg/kg

Heavy metal	Plot		
	1	2	3
Zn	46.88 ± 9.84	54.45 ± 11.43*	65.18 ± 12.43*
Cu	5.10 ± 1.17	6.10 ± 1.40	8.12 ± 1.89
Fe	76.50 ± 17.20*	131.01 ± 31.10*	145.22 ± 46.3*
Cd	0.11 ± 0.04	0.14 ± 0.06	0.23 ± 0.09*
Pb	0.42 ± 0.15	0.62 ± 0.18*	0.65 ± 0.24*
Cr	0.88 ± 0.26	0.95 ± 0.36	1.58 ± 0.68
Ni	3.72 ± 1.12	5.19 ± 1.56*	6.78 ± 1.69*

In the needles of the studied areas, a threefold increase in the content of chlorophyll a was noted. The concentration of chlorophyll b is significantly lower than the previous one. Photosynthetic pigments are sensitive to the effects of pollutants.

Carotenoids increase under stress. It was noted that carotenoids in the areas show upwards, in areas with a high content of heavy metals they are in the inerval: plots 1–3 (5.14–9.60) mg/g.

Anthropogenic pollutants cause an increase in caratinides in the needles, so the quantitative composition of caratinides can show what effect the anthropogenic load has on the plant community. And the reverse relationship is shown for chlorophyll pigments. In contaminated areas, they become less (Table 2).

Table 2. Photosynthesis pigments in needles, mg/g

Photosynthesis pigments	Plot		
	1	2	3
Chlorophyll *a*	3.25 ± 0.02	2.69 ± 0.02*	1.90 ± 0.01*
Chlorophyll *b*	2.90 ± 0.01	4.30 ± 0.03	4.90 ± 0.03
Carotenoid	6.20 ± 0.04*	7.60 ± 0.04*	7.00 ± 0.04*

The complex of anthropogenic factors has a negative impact on the populations of *Pinus sylvestris L.*

The distribution of heavy metals in the needles of Pinus sylvestris L. can be represented graphically. Figure 1 shows the distribution of pollutants (average value) in the study area. The areas where the greatest accumulation (dark color) and the least accumulation (light color) are marked. Thus, by superimposing the revealed values on the map, one can assume how heavy metals can spread and be distributed in nearby territories.

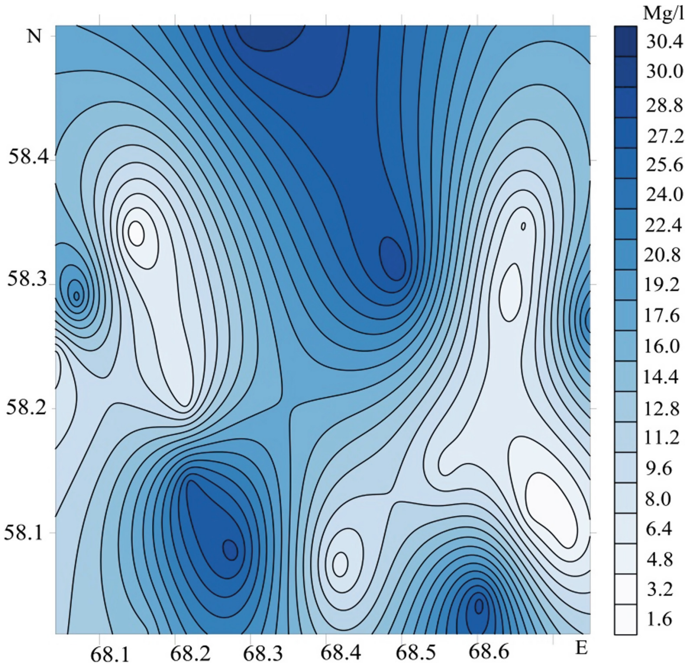

Fig. 1. Distribution of heavy metals in the needles of *Pinus sylvestris* L. of the study area (mean value), mg/kg

4 Discussion

Citing literature data on the response of plant communities to the impact of anthropogenic pollutants, many researchers noted that the chemical composition of plants reflects the elemental composition of soils. Most conifers can be used as indicators. They are observed during environmental monitoring. When studying the impact of pollutants of roads, Pinus sylvestris L. is also used as a test object. Thanks to coniferous plants, it is possible to study the state of the natural environment and other ecosystems of different nature and rank. The use of tree vegetation response to pollutants makes it possible to assess the degree of damage to populations. The choice and priority of environmental protection measures are determined on the basis of a complete environmental assessment of the state of the components of the natural environment [16, 17].

Pine trees with damaged needles are located near motor roads, and those with intact needles are located further from the road. The pine is an indicator of clean air; where the air is heavily polluted, pine needles get damaged and the lifespan of a tree decreases [18].

As a result of the research, it was revealed that the photosynthetic apparatus of Scotch pine is an indicator of the environment. Exposure to heavy metals induces and activates defense mechanisms. As a result, green photosynthetic pigments decrease and carotenoids increase. Using these data, it is possible to predict and detect environmental pollution without using chemical research methods to determine heavy metals in environmental components. [19].

5 Conclusion

As a result of the studies, it was noted that in the needles of Pinus sylvestris L. of the monitored areas, the content of heavy metals varied within the following ranges: Zn 46.88–65.30; Cu 5.10–8.12; Fe 76.50–145.22; Cd 0.11–0.23; Pb 0.42–0.65; Cr 0.88–1.58; Ni 3.72–6.78 mg/kg, the results are significant at $P < 0.05$. The characteristic specialization is Fe-Zn-Cu. The index of synanthropization of the flora of the studied phytocenoses ranges from 50 to 64%. This suggests that synanthropic species occupy most of the areas, i.e. dominate, forming a general background, in which all other types of vegetation are interspersed. The characteristic signs of an unfavorable environmental conditions, particularly gas composition of the atmosphere, are the appearance of various kinds of chlorosis and necrosis. It was found that under stressful conditions, exposure to pollutants, the concentration of carotenoids changes upwards, and photosynthesis pigments - downwards.

Differences in pigment content are significant. It is possible that the high concentration of carotenoids found in the studied objects, in areas with increased pollution, is associated and shows a protective activation of the photosynthetic apparatus. This kind of data can be used for reforestation in large areas contaminated with heavy metals.

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