

State and Environment Purifying Functions of Forest Stands Under Conditions of Polymetallic Pollution in the Industrial Center of Sterlitamak

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Abstract—Environmental degradation of urbanized areas negatively affects the population health. Air pollution is a priority among other environmental factors affecting incidence. The issue of environmental pollution by heavy metals, which exhibit high toxicity in trace amounts and have a high migratory ability and a tendency to bioaccumulation, has become increasingly urgent in recent years. The creation of sanitary-protective sectors of woody plant species should contribute to the deposition of aero-pollutants, as well as the absorption of toxicants from the soil. However, the performance of the function of a phytfilter for a long time negatively affects the vitality of trees themselves. A study of the absorptive capacity of individual species of woody plants and their reaction to the toxicants will make it possible to predict the stability of protective forest stands and justify forestry activities. This work presents the results of many years of research on the assessment of the relative living state and characteristics of the accumulation of heavy metals (Cu, Cd and Pb) with balsam poplar (*Populus balsamifera* L.) under conditions of industrial center of Sterlitamak. The metal content in the samples was determined by atomic absorption spectrometry. The biological absorption coefficient and the conversion coefficient were calculated. It was revealed that under the conditions of polymetallic pollution of the Sterlitamak's industrial center, the relative living condition of the balsam poplar stands is assessed as "weakened". The high content of metals in the soil's root layer negatively affects the vitality of trees. Despite this, poplar stands make a significant contribution to limiting the spread of pollutants in the environment. The highest content of heavy metals in healthy trees is noted in the root system, thereby contributing to the preservation of favorable concentrations of chemical elements in the aboveground organs. With an increase in the concentration of copper, cadmium and lead in the roots of weakened trees, their increased amount is also observed in the aboveground organs (branches and leaves).

Keywords—*environmental and hygiene safety, industrial pollution, heavy metals, Populus balsamifera L, sanitary protection sectors.*

I. INTRODUCTION

The deterioration of ecological state of urbanized territories negatively affects the population health [1-4]. There is evidence that residents of contaminated territories are sick more often than residents of relatively ecologically clean cities [5-6]. According to the World Health Organization (WHO), habitat quality accounts for about 15-

25% of the global diseases. At the same time, air pollution is a priority among the factors affecting human health. It is noted that the air environment quality has a direct impact on the mortality rate due to respiratory diseases, and the incidence of childhood asthma is attributed to indicators of environmental quality by WHO [7]. The "environment – human health" issue is considered one of the most urgent in connection with the increase in cancer incidence rates among residents of ecologically unfavorable regions, since some industrial toxicants have carcinogenic properties [8-10]. To date, mortality caused by malignant neoplasms has been stably associated with atmospheric air pollution by carcinogens in 11 subjects of the Russian Federation [7].

The current situation requires a more detailed and in-depth study of the distribution processes and accumulation of pollutants in environmental components. The issue of pollution with heavy metals, which exhibit high toxicity in trace amounts, have a high migratory ability and a tendency to bioaccumulation, has become increasingly urgent in the recent years. Accumulating in the body, metals can exhibit mutagenic, teratogenic and carcinogenic properties [11-12]. Once in the atmosphere (as part of industrial emissions), heavy metals are able to disperse for tens of kilometers and then settle, polluting the soil cover [13].

The creation of sanitary-protective sectors of woody plant species should contribute to the deposition of aero-pollutants, as well as the absorption of toxicants from the soil. However, the performance of the function of a phytfilter for a long time can adversely affect the vitality of the trees themselves. A study of the absorptive capacity of individual species of woody plants and their reaction to the toxicants will make it possible to predict the stability of protective forest stands and justify forestry activities.

One of the species that is widely used in creating sanitary protection sectors is balsam poplar (*Populus balsamifera* L.). This species is characterized by rapid growth, frost resistance, unpretentiousness.

We studied the state of poplar forest plantations in the conditions of various anthropogenic pollutions during 1995-2016. The purpose of this study is to assess the relative living state and characteristics of the accumulation of heavy metals (Cu, Cd and Pb) by the balsam poplar in the conditions of the industrial center of Sterlitamak.

The city of Sterlitamak is located in the Pre-Ural of the Republic of Bashkortostan and is one of the centers of the chemical and petrochemical industry of the Russian Federation. The population is 280 thousand people. Production facilities began to appear in the city in the 50s of the twentieth century. Today, environmental pollution in Sterlitamak is associated with the work of such enterprises as the Bashkir Soda Company, Sintez-Kauchuk, and the Sterlitamak Petrochemical Plant. In addition, electricity and motor transport enterprises contribute to air pollution. The volume of pollutant emissions per unit of territory in Sterlitamak in 2018 amounted to 5.6 t/ha. The volume of pollutant emissions from the city as a whole into the atmosphere over the past 5 years varied between 54.2-68.8 thousand tons per year [14]. The difficult environmental situation is caused by the location of industrial facilities without taking into account the ecological capacity of the territory.

Sterlitamak is considered as one of the regions with negative trends in the health status of residents. Our analysis of the official data of the Medical Information and Analytical Center for the Republic of Bashkortostan over the past 10 years (2009-2018) revealed high incidence rates for both adult and children. The average adult morbidity level is on average 152087.6 ± 6859.5 per 100 thousand people; the level of the general incidence of children (0-14 years) is 291568.2 ± 12913.6 per 100 thousand people. The children population is characterized by a high level of respiratory diseases. For many years, high rates have been recorded for individual conditions that occur in children in the perinatal period (653.8 ± 63.4 per 1000 children). An unfavorable situation of oncological morbidity is noted – the average indicator of the contingent of patients with malignant neoplasms of the entire population of Sterlitamak is 1924.3 ± 123.2 per 100 thousand people.

II. RESEARCH METHODOLOGY

The objects of this study were healthy and weakened balsam poplar trees. The studies were carried out at two permanent trial plots (PTP). Establishment and description of the trial plots were carried out according to generally accepted methods [15-16]. PTP No. 1 was 20 by 60 meters and was established 1-2 km away from the sources of petrochemical and chemical pollution of the industrial center of Sterlitamak. PTP No. 2 was 20 by 50 meters and was located in the zone of conditional control (20-25 km away from pollution sources). Trial plots were established in clean stands of uniform age (over 50 years old).

The assessment of the relative vital state of trees (Ln) was determined by the method of V.A. Alekseeva [17]. A visual assessment of such diagnostic features as the crown density, the presence of dry branches on the trunk, and the degree of leaf blades' damage was carried out. The category of the vital state of an individual tree was determined by the auxiliary table (Table I).

TABLE I. AUXILIARY TABLE FOR DETERMINING CATEGORIES OF TREES

Category	Diagnostic features		
	Crown density, %	Dry branches, %	Leaf damage degree, %
Healthy	86–100	0–15	0–10
Weakened	56–85	16–45	11–45
Strongly weakened	21–55	46–70	46–65

Category	Diagnostic features		
	Crown density, %	Dry branches, %	Leaf damage degree, %
Dying	1–20	71–99	71–100
Dead	0	100	No leaves

To study the accumulation of metals during the growing season, repeated re-selection of leaves, branches and roots was performed for chemical analysis. At the same test sites, soil samples were taken simultaneously with the plant ones. The selected samples were dried to an air-dry state [18]. The metal content in the samples was determined by atomic absorption spectrometry on an AAC-ZEEnit-650 analyzer. Soil pH was determined by potentiometric method.

To evaluate the efficiency of metal absorption, we used the biological absorption coefficient (BAC), which is the quotient of dividing the metal content in the ash of plant material by its total content in the root layer of the soil. When grouping chemical elements in series according to the intensity of biological absorption, five gradations are used [19]:

- Elements of biological accumulation (BAC > 1):
 - 1 group. BAC = 100–10 — elements of energetic accumulation;
 - 2 group. BAC = 10–5 — elements of strong accumulation;
 - 3 group. BAC = 5–1 — elements of weak accumulation.
- Elements of biological capture:
 - 4 group. BAC = 1–0.1 — elements of average capture;
 - 5th group. BAC = 0.1–0.01 — elements of weak capture.

To characterize the processes of transition of metals from roots to the aerial part, a transition coefficient (Ct) was calculated, which is equal to the ratio of the metal content in the aboveground phytomass and in the roots.

III. RESULTS

Studies have shown that under the conditions of polymetallic pollution of the industrial center of Sterlitamak, the relative vital state (RVS) of the balsam poplar stands is characterized as “weakened” (Ln = 65.2%) (Table II).

TABLE II. RELATIVE VITAL STATE OF BALSAM POPULAR UNDER CONDITIONS OF POLYMETALLIC POLLUTION OF THE INDUSTRIAL CENTER OF STERLITAMAK AND IN THE AREA OF CONDITIONAL CONTROL

№ PTP	Number of trees at the PTP by category, pcs.						RVS of plantings	
	In total	Healthy	Weakened	Strongly weakened	Dying	Dead	Ln, %	Category
PTP №1	20	5	8	6	0	1	65.2	“Weakened”
PTP №2	20	10	7	3	0	0	80.5	“Healthy”

As part of the studied stand, the vast majority of trees belonged to the categories of “weakened” and “strongly weakened”. It also included forest stags. Only one fourth of

the forest stand belonged to the category of “healthy” trees. Observations showed that under the influence of industrial pollution, poplar has a decrease in crown density (up to 30%) and the formation of a large number of dead branches (35.25%). Dying and dead branches are concentrated in the upper, middle and lower parts of the crown. More than 35% of the area of leaf blades is characterized by the presence of chlorosis and necrosis. They are brown and dark brown in some places. In addition, changes in the structure of root systems in the soil layer of 0-10 cm occur. Changes are manifested in a decrease in the proportion of conductive, semi-skeletal, and skeletal roots in healthy trees. The bulk of the absorbing roots was located at a depth of 20-30 cm. It can be predicted that the state of the stands in the future will deteriorate as due to pollutants’ impact.

The RVS of poplar stands in the zone of conditional control is characterized as “healthy” ($L_n = 80.5\%$). The category of “healthy” trees included half of the studied population. 7 trees were classified as “weakened”, 3 as “strongly weakened”. Trees in the conditional control zone have a better formed crown (crown density of more than 80%) and fewer dead knots on the trunk (up to 10%). The average area of affection of leaf blades was 10.04%, which is three times lower than the same indicator in the territory of the PTP No. 1.

Table III shows the average levels of heavy metals in the soil cover under poplar stands. It should be noted that typical and leached chernozems prevail in the study area. The pH value of the soil solutions varied between 6.55-6.90 pH units.

TABLE III. CONTENT OF GROSS FORMS OF METALS (MG/KG) IN THE SOIL COVER OF BALSAM POPLAR

Depth, cm	PTP №1			PTP №2		
	Cu	Cd	Pb	Cu	Cd	Pb
0-10	217.00	6.90	59.70	26.70	1.50	7.56
10-20	201.00	2.13	39.60	24.30	0.35	6.39
20-30	179.00	0.08	28.80	18.60	0.12	4.75
30-40	165.00	0.05	14.00	18.20	0.60	2.05
40-50	102.00	0.02	1.00	14.60	0.10	2.18

As can be seen from Table III, a higher metal content is observed in the soil layer of 0-10 cm. Accumulation of toxicants in the surface layer of the soil cover indicates the anthropogenic nature of the pollution. The data of PTP No. 1 and No. 2 differ to a large extent. So, under the conditions of polymetallic pollution of Sterlitamak, the concentration of copper and lead is 8 times and cadmium – 4.5 times higher than in the conditional control zone.

According to the content of Cu, Cd and Pb, aboveground and underground organs in healthy and weakened trees are arranged in the following series: roots > branches > bark > leaves. At the same time, the roots of healthy trees accumulate metals 2-3 times more than the roots of weakened trees. It can be assumed that under the conditions of polymetallic pollution, the root system plays an important role in protecting plants from the excess supply of toxic metals from the soil. It is a fact that the toxicity of lead and cadmium is associated with a violation of fundamental biological processes, such as photosynthesis, growth, mitosis, etc. The visible symptoms caused by the increased content of these metals in plants are growth retardation, damage to the root system, and leaf chlorosis. The toxic effect of copper is manifested in a decrease in the formation of phytomass, a

decrease in the content of chlorophyll and hydration of tissues, and inhibition of the absorption of ions of some other metals and their translocation [20-22].

The intensity of the biological absorption of metals from the soil was estimated using BAC, which allows you to indirectly estimate the degree of accessibility of an element for a plant and its implementation in the soil-plant system. Calculations revealed that $BAC < 1$ for the studied metals, that is, they act as elements of medium capture.

For copper, BAC varies from 0.16 to 0.85, cadmium – from 0.64 to 0.86; lead – from 0.77 to 0.83. Moreover, the highest BAC values are characteristic of healthy trees grown on contaminated soil. It should be noted that the coefficient of biological absorption is not constant and can vary depending on time (on the vegetation phase), plant age, soil characteristics.

Results of chemical analysis showed that under the conditions of polymetallic pollution in leaves and branches of healthy trees, the average copper content is 22.00-29.00 mg/kg, cadmium is 0.30-0.70 mg/kg, and lead is 9.00-12.00 mg/kg. Metal content in the aboveground organs of weakened trees is higher: copper – 32.00-38.00 mg/kg, cadmium – 1.00-1.50 mg/kg, lead – 18.00-23.00 mg/kg. The observed increase in the metal content in the aboveground organs of weakened trees is probably associated with a violation of the root barrier function. This is confirmed by indicators of the coefficient of metal transition from roots to leaves. The average Ct value of copper in weakened trees is 0.56; cadmium – 0.58; Pb – 0.58. This indicator is 2 times lower in the healthy trees – 0.28; 0.24 and 0.36; respectively. The obtained values of the transition coefficients indicate that the degree of translocation from underground to aboveground organs does not differ much between the studied metals.

The amount of metals that were accumulated during the growing season was calculated in order to assess the depositing role of balsam poplar plantations. Calculations showed that under the conditions of industrial pollution, 1 ha of poplar plantations over the age of 50 years is able to accumulate in leaves: Cu – 3.35 kg, Cd – 0.11 kg, Pb – 4.09 kg.

A well-developed root system, high yield and transpiration activity allow us to recommend the use of balsam poplar for phytoremediation of soils. Significant absorption capacity of poplar leaves can be used to reduce the air pollution.

IV. CONCLUSION

Studies showed that the RVS plantations of balsam poplar under the conditions of polymetallic pollution of the industrial center of Sterlitamak are estimated as “weakened”. The high content of toxic metals in soils negatively affects the vitality of trees, contributing to a decrease in crown density, formation of a large number of dead branches, and damage to leaf blades. Despite this, poplar sanitary-protective sectors make a significant contribution to limiting the spread of pollutants, accumulating them in aboveground and underground organs, thereby fulfilling the environmental purification function.

The highest content of heavy metals in the healthy trees is noted in the root system, which contributes to preservation of favorable concentrations of chemical elements in the aboveground organs. With an increase in the concentration of

copper, cadmium and lead in the roots of the weakened trees, their increased amount is also observed in the aboveground organs (branches and leaves), which is probably due to a violation of the barrier function of the roots.

Results of this study make it possible to predict the development of progressive degradation of poplar stands in the sanitary-protective sectors on the territory of the industrial center of Sterlitamak and recommend the need for their reconstruction.

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