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Short communication

Species features of bioaccumulation of heavy metals in leaves of poplar *Populus canadensis* Moench and ash *Fraxinus americana* L. in the urban ecosystem

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Abstract. The search for heavy metal concentrator plants is important in terms of diagnostics and remediation. In the course of the work, the gross contents of Cd, Zn, Ni, Cu, Pb were measured in the leaves of poplar *Populus Canadensis* Moench and ash *Fraxinus Americana* L. These trees are often used in the landscaping of populated areas. Air-dry samples of tree leaves collected during one growing season at 5 sites located on the territory of Kirov (Russia, Kirov oblast) were studied by atomic absorption spectroscopy. Zinc was accumulated to a greater extent in poplar leaves. Maximum accumulation of zinc was noted in the industrial areas of the city. Ash leaves largely accumulated copper and lead, the content of which was high throughout.

Keywords: anthropogenic pollution, urban vegetation, bioaccumulation, cadmium, zinc, nickel, copper, lead

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Краткое сообщение

Видовые особенности биоаккумуляции тяжелых металлов листвой тополя *Populus canadensis* Moench и ясеня *Fraxinus americana* L. в условиях урбоэкосистемы

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Аннотация. Поиск растений-концентраторов тяжелых металлов (ТМ) имеет значение с диагностической и ремедиационной сторон. В ходе работы были измерены валовые содержания Cd, Zn, Ni, Cu, Pb в листьях тополя канадского *Populus canadensis* Moench и ясеня американского *Fraxinus americana* L. – деревьев, часто используемых в озеленении населенных мест. Методом атомно-абсорбционой спектроскопии исследованы воздушно-сухие биопробы листьев деревьев, собранные в течение одного вегетационного сезона на 5 участках, расположенных на территории г. Кирова (Россия, Кировская область). Показано, что в листьях тополя в большей степени аккумулировался цинк, максимальное накопление которого установлено в промышленных зонах города. Листья ясеня в большей степени накапливали медь и свинец, содержание которых было высоким на всех участках.

Ключевые слова: антропогенное загрязнение, городская растительность, бионакопление, кадмий, цинк, никель, медь, свинец

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Introduction

The study of a part of the biogechemical cycle of heavy metals (HMs) in the soil-plant system is of great importance because many sectors of the economy cannot eliminate these widespread pollutants from production cycles. As a result, they invade the environment and cause various environmental consequences. Today, the main trends demonstrating the ability of HMs to migrate into a plant are known and convincingly proven. For instance, the bioavailability of HMs increases due to the growing soil acidity, the migration ability of HMs decreases in soil rich in organic matter, perennial plants accumulate HMs to a greater extent than non-perennial plants (Hazardous and trace materials..., 2022; Ilyin, 2012; Klimova, 1999).

Modern research are focused on the ecosystem consequences of HM migration in the soil-plant system. For example, the Yunan poplar *Populus yunnanensis* Dode growing on soils contaminated with cadmium has a reduced content of volatile organic compounds in its leaves that makes leaf-eating insects avoid it (Lin et al., 2022). It has been proven that symbiotic fungi in the mycorrhiza of woody plants are natural biofilters reducing the toxic effect of HMs (Szuba et al., 2020).

The data on modification of environmental interactions under the influence of toxic stress need to be supplemented with the information on plant species that are most resistant to existing pollution and, possibly, contribute to the phytoremediation of soils saturated with pollutants. Positive results on phytoremediation of soils contaminated with HMs using plantings of poplar clone Monviso (a hybrid of the noble poplar *Populus generosa* Henry and black poplar *P. nigra* L.) were obtained in Italy in terms of HMs phytostabilization, improvement of soil quality as regards the organic carbon content as the structure and activity of the microbial community (Ancona et al., 2020).

The goal of our work was to determine the species features of HM accumulation in the leaves of Canadian poplar *Populus Canadensis* Moench and American ash *Fraxinus Americana* L. during the growing season in the urban ecosystem.

Materials and methods

The study sites were located within the urban ecosystem of the city of Kirov (Kirov oblast, Russia) situated in the southern taiga zone, the subzone of coniferous-deciduous forests. A total of 5 sites (25×25 m) were chosen: one in the city park (Victory Park), three in transport and industrial zones (areas of the machine-building plant “VMP Avitek”, the electric machine-building plant “Lepse”, “Kirov non-ferrous metal working plant” stock company, and one site in a conditionally background territory – a forested area in the suburbs of the city (Dendrological park).

At each site, leaves of poplar *P. canadensis* and ash *F. americana* were collected in September 2021. A total of 10 trees of the selected species were used in each plot; 10 leaves were taken from each tree. The leaves selected from the site represented a combined sample (100 pieces), which was averaged by mechanical homogenization. In the biomass of leaves dried to an air-dry state, the gross content of heavy metals (Cd, Zn, Ni, Cu, Pb) was determined using the atomic absorption spectrometer “Spektr-5” (Russia) in accordance with the generally accepted method[1]. The result of the analysis was presented as the average value of the element content between two parallel samples with an error according to the method.

Since sanitary and hygienic regulation of HM content in plants is provided only for agricultural plants, our data on the content of chemical elements in the leaf biomass were compared with the minimum values of the toxic level of bioaccumulation proposed by A. Kabata-Pendias (2010) for plant biomass.

The reliability of the results was ensured by the minimum required volumes of biological samples, the performance of analyzes in the accredited laboratory of Vyatka State University (Kirov), compliance with the requirements for the conditions for performing such analyzes, analytical repetitions and assessment of the acceptability of the difference between them.

[1] Guidelines for the determination of heavy metals in soils of agricultural lands and plant products, 1992. 2nd edition, revised and expanded. TsINAO, Moscow, Russia, 63 p.

Results and discussion

Our data suggest that poplar to a greater extent accumulates zinc (Fig. 1), while ash leaves – copper and lead (Fig. 2). The occurrence of these trends in the studied sites varies. For instance, the accumulation of zinc in poplar leaves is noted in public parks near plants dealing with different metal processing cycles.

According to A. Kabata-Pendias (2010), minimum toxic levels of bioaccumulation of HMs in woody plants make up 5 mg/kg for cadmium, 100 mg/kg for zinc, 10 mg/kg for nickel, 20 mg/kg for copper and 30 mg /kg for lead. Thus, significant toxic levels of accumulation were recorded near the plants "Lepse" (excess was 2.23 times) and "Avitek"(1.92 times), where significant concentrations of mobile forms of zinc were also detected in soil: 30 ± 10 mg/kg and 6.2 ± 2.1 mg/kg, respectively (in conditionally background soil – 1.1 ± 0.4 mg/l) (Gornostaeva et al., 2022). At the same industrial sites, ash leaves also accumulated zinc greater than nickel and cadmium, but the level of accumulation remained within 0.26–0.53 of the conventional reference value.

Other researchers have confirmed our data on the tendency to significant zinc accumulation by trees of the genus *Populus*. Based on physiological responses (gas exchange, amount of chlorophyll and carotenoids, root growth), black poplar *Populus nigra* L. is more sensitive to the hydroponic effect of zinc than Matsuda willow *Salix matsudana* L. (Palm et al., 2021). The mechanism of zinc accumulation in poplar leaves is described in the work of Y. Suo et al. (2021): delta poplar *Populus deltoides* W. Bartram ex Marshall cultivar "Xianglin 90" grown in a mine tailing pond increased the rhizosphere mobility of Cd and Zn by 5.49% and 4.29%, respectively, compared to the total soil volume. This explains the ability of poplar to bioaccumulation and translocation of these metals in the root-sprout system.

At the same time, there are published data on the insignificant accumulation of Cd, Cu, Pb and Zn by common ash *Fraxinus excelsior* L. under conditions of metallic soil contamination (Mertens et al., 2004). Discrepancies between our results and this information may be caused by environmental factors (soil mineral composition, humidity, average annual temperature) that affect the bioavailability of metals and their accumulation in plant parts.

Plants accumulate HMs both from air and soil. The atmosphere can be a direct source of pollutants on the surface of leaves (adsorption) and in their internal tissues (true accumulation). During the study period, the average and average monthly concentrations of heavy metal aerosols in the atmosphere did not exceed permissible standards[2]. However, emissions from plants within the established standards, along with the vehicle load, are likely to be the reason for heterogeneous accumulation of heavy metals in soils of the city of Kirov. It was shown that the soil near the machine-building enterprise "Avitek" and "Kirov non-ferrous metal working plant" accumulate much more metals than soils of the conditionally background territory of the Dendrological park: zinc concentrations: 6.2 ± 2.1, 36 ± 12 and 1.1 ± 0.4 mg/kg, respectively; copper content: 0.50 ± 0.10, 6.0 ± 1.4 and 0.06 ± 0.02 mg/kg (Gornostaeva et al., 2022). At the same time, our data show that the bioaccumulation of HMs by ash leaves is often within the background, and in the case of zinc and copper, the background plants accumulate more elements than the leaves of trees in other parts of the city (Fig. 2). Apparently, the increased bioaccumulation of copper and lead by ash is of a species feature when accumulation occurs regardless of pollution, i.e. as a true concentrator. Increased migration of HMs from soil of the conditionally background area into ash leaves may be associated with the pH level of the upper soil horizon (Gornostaeva et al., 2022) – 4.9 ± 0.2 units pH, as compared to 6.1–7.1 at other urban sites. It is common knowledge that an acidic reaction of the environment increases the concentration of bioavailable forms of many microelements in soil solution (Hazardous and trace materials..., 2022).

The species feature of the bioaccumulation of various HMs by woody plants is known for *Populus nigra*, which is the best accumulator for Mn, Zn and Cd, oriental thuja *Thuja orienta*lis (L.) Endlicher – a phytoextractor for Fe, evergreen cypress *Cupressus sempervirens* L. – a bioaccumulator of Pb (Saba et al., 2015). The mechanisms of differences in accumulation of some metals are explained by the level of expression of the MTP gene, which encodes CDF (cation diffusion facilitator) protein affecting HMs transport through the phloem of a tree (Yang et al., 2021).

[2] On the state of the environment of the Kirov region in 2021, 2022. Regional report. Ministry of Environmental Protection of the Kirov Region, Kirov, Russia.

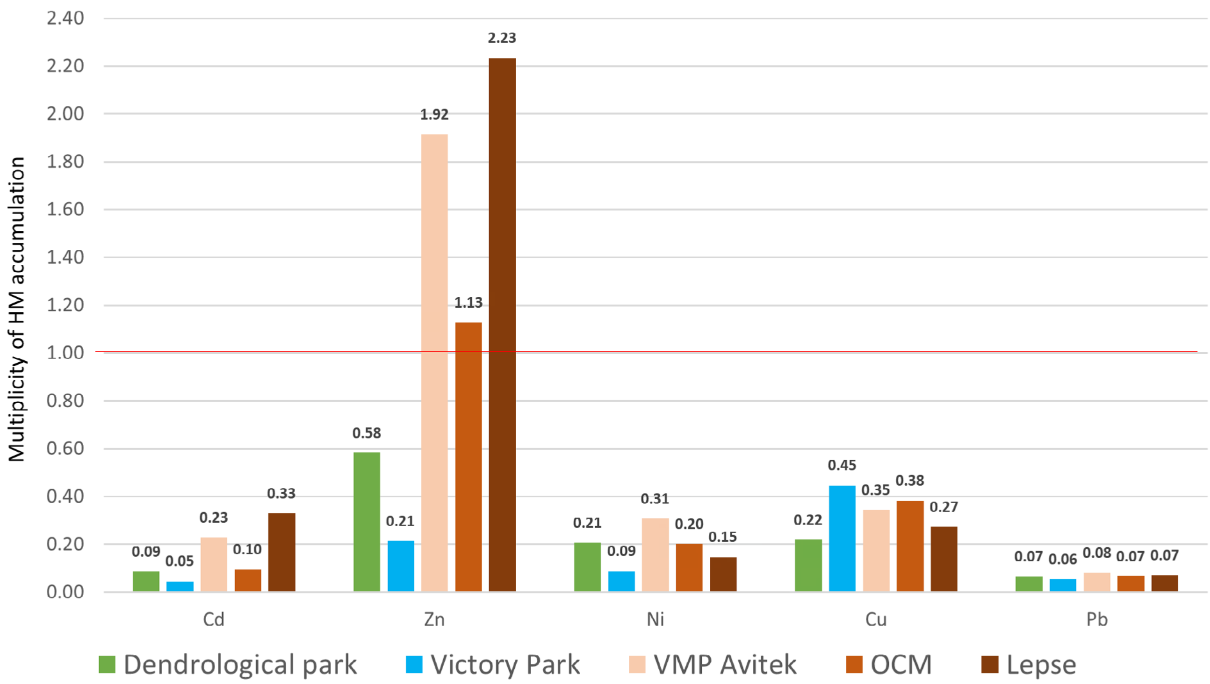

Fig. 1. Multiplicity of HM accumulation by *P. canadensis* poplar leaves relative to the minimum toxic level according to Kabata-Pendias, 2010. The red line indicates the minimum toxic level of HM content in plants.

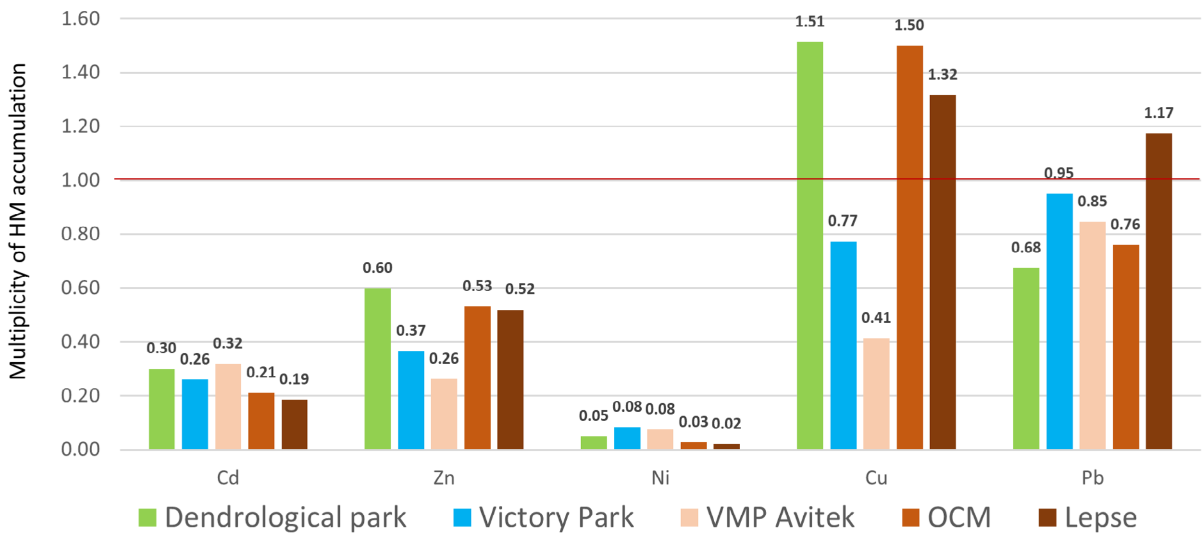

Fig. 2. Multiplicity of HM accumulation by *F. americana* ash leaves relative to the minimum toxic level according to Kabata-Pendias, 2010. The red line indicates the minimum toxic level of HM content in plants.

Conclusion

It was shown for the first time that common in urban landscaping trees (Canadian poplar and American ash) have specific characteristics of HMs bioaccumulation in their foliage. Poplar foliage accumulates zinc if trees grow on soils contaminated by heavy metals. Ash can transport copper and lead into its leaves regardless of soil contamination with these elements. The presented information may be useful when developing phytoremediation interventions for anthropogenically loaded urban soils. To confirm the identified trends and quantitatively describe their dynamics, it is necessary to conduct multi-year research.

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