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Some Regularities in the Accumulation of Lead in Urban Plants (by Example of Vladivostok)

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Abstract—The ability of plants to accumulate lead is studied for 128 plant species from 44 families and 28 genera of the Far Eastern flora. A significant variation in the content of lead in the assimilation organs of plants is observed; the variation is within 0.81–25.67 mg/kg of air-dry matter. The main regularities in the accumulation of metals by plants of different systematic taxa and biomorphological groups are revealed. The groups of plants according to the intensity of lead accumulation and the types of metal-concentrating species are identified. The species promising for phytoremediation and phytoindication in an urban environment are recommended.

Keywords: lead content in plants, urban environment, phytoindication of chemical pollution, geochemical systematics of plants, phytoremediation.

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For many decades lead has been the object of attention for scientists from different scientific fields as a major pollutant and a test element in the assessment of human-caused pollution of biotic and abiotic components of ecosystems. Owing to the widespread use of the metal in the economic activities of mankind, lead pollution has been imposing an ever increasing influence on the environment exceeding the natural migration cycle for many centuries. According to V.V. Dobrovol'skii [1], the annual extraction of Pb is 2400000 t/year, while the removal of soluble forms by river runoff is 37000 t/year, and the annual capture by land plants is 430000 t/year. At the present time, in our opinion, the issues of life safety and health in urban areas, where “man-made” lead geochemical anomalies on the scale close to natural ones were formed, are especially important.

Public health standards include lead in the group of the most toxic elements of the first degree of danger. All soluble compounds of Pb are poisonous.

The main environmentally stabilizing factors which transform and conserve man-made pollution in both natural and anthropogenically transformed ecosystems are known to be the main biotic components of ecosystems, i.e., the vegetation and soil.

At present, national and foreign literature has accumulated a large amount of factual material for assessing the environmental conditions and heavy metal content in plants and soils of different cities of Russia and the rest of the world [2–8, etc.]. The vast majority of the available data reflect regional features of the phytogeochemistry and biological cycle of heavy metals. No similar systemic studies have been conducted in Vladivostok, although the modern ecological situation in the city is far from optimal. According to the available data [9–11], the environmental condition of Vladivostok soil corresponds to the moderately dangerous category of pollution with a high level of a number of heavy metals, including lead. Approximately 30% of the residential zone (RZ) of the city is contaminated with lead to various degrees. There is evidence [12] that the concentration of lead in the air of the city exceeds the maximum permissible concentration.

Despite the fact that in recent decades lead has been one of the most popular objects of research, its role in the life of plants, the mechanisms of entering the tissue, and the organism's response to an excess content of lead in the environment are still not fully understood. It is known that lead, as a typical diffused element, is present in all abiotic and biotic components of the environment and is included in the phytomass of all species of plants. Its average content in land vegetation for air-dry matter is $2.5 \times 10^{-4}\%$ and for living phytomass is $1.0 \times 10^{-4}\%$ [13]. Lead concentration of 5–10 mg/kg is sufficient for normal functioning for most plant species; 30–300 mg/kg is toxic [14]. It is known that most of the species in background growth conditions belong to a group of exceptional plants according to the mode of lead accumulation. They are characterized by a low content of metal in shoots regardless of the high concentrations in the environment. Most plants accumulate lead in the underground part; the main way of its absorption is passive via the root system [14–16]. The metal taken up by the root moves up to the endodermis primarily through the apoplast at a different rate depending on the chemical composition of cell membranes. Excessive lead accumulation in them can reduce their plasticity and inhibit the growth of tension. When there is a lethally high content of lead in soil, the decisive factor of its penetration to the roots is the affinity of the metal to the cell walls; in the case of semilethal, it is the presence of physiological barriers [16, 17].

The available scientific literature of recent years also gives information that lead is a potent stressor, forcing the plant to include adaptive coping mechanisms. As noted in the scientific review by I.V. Seregin and V.B. Ivanov [1], the toxic effects of lead on the metabolism is generally similar to that of most heavy metals and is different only in the ratio of affected processes, and in some cases (e.g., inhibition of several enzymes) functionally, in the mechanism of action. Lead affects the absorption of water by plants and inhibits the processes of photosynthesis [18, 19]. Its high content in tissue leads to a decrease in chlorophyll content, functional disturbances in the pigment complex, the inhibition of growth processes, and a decrease in vitamin C and provitamin A [20]; it can also can inhibit breathing and sometimes contribute to an increase in the content of cadmium and a decrease in zinc, calcium, phosphorus and sulfur [21].

The purpose of the present research is to evaluate the accumulative capacity of higher plants in relation to lead in urban environments and to establish plants which concentrate lead and adequate indicators of the ecological condition of the urban environment.

MATERIALS AND METHODS

Some of the results of a complex ecological and biological monitoring of vegetation of the urban agglomeration of Vladivostok, which has been carried out for many years, are presented in the present paper. The study covers most of the residential zone of the city in varying detail. The most common plant communities of the suburban forest park zone (PZ) were selectively examined as standard conditions of the local environmental background (LEB). Chosen were 145 plots in the city and 33 plots in natural forests. Selected were 1200 samples of plants and 200 of the soil in the green area of the city.

The samples were taken during a short period in late July to early August. The samples of leaves (needles) were collected from 5–10 plants of each tree or shrub species on all four sides of the crown. The sample of conifers consisted mostly of 1- to 2 (3)-year-old needles. The aboveground part was taken for the analysis of herbaceous plants. In addition, herbage from ten plots 1 m^2 in size was cut at each sampling; after drying, it became a mixed sample. To estimate the proportion of the dust component in the balance of man-imposed penetration of the element in the plant, the samples were washed after selection in distilled water. The analysis of samples was carried out by the atomic absorption method in acid extracts of plant ash.

At the same time, mixed samples of soil from the upper horizons up to the depth of 10–15 cm were taken at each test area. Soil samples were also analyzed by the atomic absorption method for the maintenance of the gross forms of the metal after the decomposition by the mixture of concentrated acids.

The correlation of metal content in plants and the corresponding soil resulted in the calculation of the biological absorption coefficient (BAC) of lead.

The results of a survey of trees and shrubs, which have priority in the balance of technogenic elements in urban ecosystems, are presented and discussed in the work. The total number of species, evaluated from the point of view of their lead accumulative ability is 128, which corresponds to 70% of the total composition of urban areas and 94% of the forested dendroflora, which was previously established by us in [22]. These species are, as a rule, widely (absolute incidence on the plots of more than 25%) or moderately (incidence of 5–25%) distributed in the urban plantings. Depending on the occurrence, they are represented by 1–105 samples.

The set of individuals of one species living within the RZ was conventionally regarded as a dependent urban population, and within the PZ, as a natural population of the species.

The analytical data were processed by methods of multivariate statistical analysis using the Excel (package Data Analysis) and STATISTICA 6.0 computer programs.

In order to evaluate the intensity of lead accumulation by different plant species, all data samples was divided into quartiles, according to which the following groups of species were identified: low (first quartile), low or moderately low (second quartile), high or moderately high (third quartile), and high (fourth quartile) metal content.

RESULTS AND DISCUSSION

The analytical data show considerable variability of lead content in the assimilative organs of trees and shrubs in the city: 1.24 (*Acer tegmentosum* Maxim.*)–25.67 mg/kg of air-dry matter of leaves (*Crataegus pinnatifida* CK Schneid.). The variability coefficient for the sample of 77 species is 44%. We can note the high intrapopulation variability of lead content in many urban populations, reaching the highest values for *Robinia pseudoacacia* L. and *Pinus sylvestris* L.: 115 and 145% respectively. Both are introduced species with high prospects of naturalization in the local climatic conditions. Here, 57% of urban trees *Robinia pseudoacacia* L. refer to moderate and 41% refer to very weak; for pine, the indexes are identical—27 and 58%. It is important to mention that pine had 16% drying plants [22]. It also had the absolute maximum of lead content, which was recorded on one of the plots of urban vegetation and came up to 96.73 mg/kg.

The lead content in the leaves of *Robinia pseudoacacia* L., *Aesculus hyppocastanum* L., *Morus alba* L., *Sambucus racemosa* L., *Syringa vulgaris* L., *Physocarpus opulifolia* (L.) Maxim., *Swida alba* (L.) Opiz, and *Spiraea salicifolia* L correspond to average levels in assimilation organs of woody plants ((11.50 ± 0.57) mg/kg). All listed species, except for the last two, are introduced to the region of research. Two species, *R. Pseudoacacia* and *P. Opulifolia*, are widely represented in urban plantings of Vladivostok. *P. Opulifolia* is a dominant among shrub plantings (incidence of 34.8%). The names are given according to the Plant Record [23] with additions for several species of flora from other regions described by S.K. Cherepanov [24].

Eighteen tree species were included in the group of plants with high content of lead (mg/kg air-dry matter of leaves, needles):

Crataegus pinnatifida Bunge	25.67
Corylus heterophylla Fisch. et Trautv.	24.38
Microcerasus tomentosa (Trunb.) Eremin et Juschev***	24.30
Cerasus sargentii (Rehd.) Pojark.	21.74
Padus maackii Mill.***	19.97
Deutzia amurensis (Regel) Airy Shaw	19.94
Betula costata Trautv.	19.79
Crataegus maximowiczii C.K. Schneid.	19.15
Pinus koraiensis Siebold et Zucc.	18.28
Lonicera maackii (Rupr.) Herd.***	18.22
Philadelphus tenuifolius Ropr. et Maxim.***	17.77
30 *Abies holophylla* Maxim.	17.17
Euonymus pauciflora Maxim.	16.56
Euonymus maackii Rupr.**	16.43
Pinus sylvestris L.**	16.22
Weigela praecox (Lemoine) Bailey***	14.90
Larix sp.**	14.07
Padus avium Mill.	14.07

The majority of conifers (except fir trees), hydrangea, 50% of the species composition of euonymus, 40% of caprifoil, and 38% of roses are represented in the species composition of the group marked on the plots of RZ. Almost half of the group according to their participation in the urban stands belongs to moderately distributed species with a moderate*** or low** abundance in the urban photosyntheses. Most of them (except for *P. Tenuifolius*) have higher intrapopulation variability in lead content (59–145%), which, to some extent, can characterize these types as flexible to lead contamination of the environment.

The group of high (close to moderate) lead content (10.59–13.61 mg/kg of air-dry matter) is represented by 20 species, including widespread in urban gardening *Ulmus japonica* (Rehd.) Sarg., *Physocarpus opulifolia* (L.) Maxim., *Betula platyphylla* Sukacz., and *Robinia pseudoacacia* L. The group consists of 7 of 13 introduced species tested for lead content. In addition to previously mentioned *P. Opulifolia* and *Robinia*, they are *Acer negundo* L., *Populus alba* L., *Morus alba* L., *Aesculus hyppocastanum* L., and *Syringa vulgaris* L.

The group of trees and shrubs with low metal content in leaves (8.46–10.53 mg/kg) brings together 18 species. All of them are typical representatives of the Far East dendroflora; many of them are the main forest-forming species of coniferous and deciduous forests of the south of the Russian Far East: *Quercus mongolica* Fisch. ex Ledeb., *Fraxinus mandshurica* Rupr., *F. rhynchophylla* Hance, *Kalopanax septemlobus* (Thunb.) Koidz., *Phellodendron amurense* Rupr., *Juglans mandshurica* Maxim., *Alnus hirsute* (Spach) Fisch. ex Rupr., *Populus Koreana* Rehd., *P. tremula* L., *Armeniaca mandshurica* (Maxim.) B. Skvortz., *Acer mono* Maxim., *Pyrus ussuriensis* Maxim., *Malus mandshurica* (Maxim.) Kom., *Ligustrina amurensis* Rupr. Manchurian ash, etc. *F. Mandshurica* with an absolute absorbability of on 58.6% on the test areas dominates the green areas of Vladivostok: it forms two-thirds of the plantings around streets and sidewalks. *F. Rhynchophylla* is also widely distributed in urban green areas with the occurrence in urban photosyntheses of 25.4%.

The group of plants with low lead content contains 20 species, 13 of which are singly or rarely found in the urban parks (absolute incidence on the sample plots of 5% or less*, mg/kg):

Picea sp.*	8.15
Catalpa bignonioides Walt.* (introduced species)	8.03
Spiraea ussuriensis Pojark.*	7.99
Forsythia suspense Vahl.* (introduced species)	7.92
Maackia amurensis Rupr. et Maxim.*	7.86
Syringa oblate Lindl. (introduced species)	7.77
Acer ginnala Maxim.	7.67
Eleutherococcus senticosus (Rupr. et Maxim.)*	7.45
Populus maximowiczii A. Henry*	6.96
Sorbus pochuashanensis (Hance) Hedl.*	6.69
Carpinus cordata Blume	6.31
Micromeles alnifolia (Siebold et Zucc.) Koehne	5.95
Corylus mandshurica Maxim.*	5.84
Lespedeza bicolor Turcz.	5.64
Fraxinus pennsylvanica Marsh (introduced species)	5.37
Amorpha fruticosa L.* (introduced species)	5.14
Aralia elata (Miq.) Seem.*	5.10
Acer pseudosieboldianum (Pax) Kom	5.07
Salix caprea L.*	2.77
Acer tegmentosum Maxim.*	1.24

Most of these species are located near public buildings and residential areas with minor or moderate anthropogenic and technogenic level of contamination of ecosystems. The group includes five introduced species of exotic species with a high life status.

The comparison of the obtained data with that available in the scientific literature showed that the lead content in the plants of Vladivostok urban ecosystems is much higher than the clarke values for terrestrial plants [13] and is close to the values given by several authors for the green areas of Russian capital cities. Thus, according to different authors, the leaves (needles) of trees and shrubs in the green areas of St. Petersburg have 0.88–28.80 [25] and 8.78–52.76 [6] mg/kg; the trees of Moscow have 1.1–7.0 [26] and 2.5–11.0 [7] mg/kg of lead. An examination of typical urban plants in Irkutsk, which is close in size and population to Vladivostok, showed lower levels of lead content [8]: larch and pine needles had 0.21–3.04 mg/kg, and poplar and birch leaves had 0.28–5.16 mg/kg.

The average lead content in the leaves (needles) of 79 species of woody plants surveyed in the suburban forest phytocenoses in Vladivostok is (6.45 ± 0.49) mg/kg of dry matter, varying from 0.81 (*Armeniaca mandshurica*) to 15.07 mg/kg (*Rubus sachalinensis* Levl.) The absolute maximum in the metal concentration (24.61 mg/kg) was noted on one of the plots on *Ribes mandshuricum* (Maxim.) Kom. The coefficient of variation of Pb for the total sample is 54%. Its variability is significantly higher in the inner populational samples, where it reaches a maximum for *Maackia amurensis* (147%), *Juglans mandshurica* (117%), *Salix caprea* (102%), and *Pinus koraiensis* (96%).

High variability (85%) is also characteristic for natural populations of *Quercus mongolica*, which is the dominant of forest park phytocoenoses. It comes to 1.40–20.11 mg/kg with an average of 5.31 mg/kg dry matter. The most stable metal content was observed in the natural populations of *Deutzia amurensis* (9%) and *Schisandra chinensis* (Turcz.) Baill. (10%).

In the suburban forest phytocenoses under conditions of Vladivostok, the group of plants with a high content of lead in assimilation organs (9.07–15.06 mg/kg) is composed of 19 species of woody plants of the southern Russian Far East. Just as in the case of urban ecosystem conditions, 58% of the species composition is formed by representatives of the families of roses (*Physocarpus amurensis* (Maxim.) Maxim., *Rubus crataegifolius* Bunge, *R. sachalinensis* Levl., *Sorbaria sorbifolia* (L.) A. Br., *Padus avium*), caprifoil (*Lonicera maackii*, *L. caerulea* L., *Abelia coreana* Nakai), and euonymus (*Euonymus sacrosancta* Koidz., *E. macroptera* Rupr., *E. Maximoviczi-ana* Prokh.) In addition, this group includes Ribes mandshuricum (Maxim.) Kom., *Deutzia amurensis*, *Rhamnus davurica* Pall., *Corylus heterophylla*, *Ribes mandshuricum* (Maxim.) Kom., *Deutzia amurensis*, *Rhamnus davurica* Pall., *Corylus heterophylla*, and two vines typical of coniferous–deciduous forests of Primorye—*Actinidia kolomikta* (Maxim.) Maxim. and *Vitis amurensis* Rupr.

The group of plants with high levels of lead in assimilation organs (0.81–3.75 mg/kg) in background conditions combines 21 species. It is represented by two-thirds by species of the birch family (*Alnus hirsute* (Spach) Fisch. ex Rupr., *Betula costata*, *B. davurica* Pall., *B. platyphylla*), pine (*Abies holophylla*, *A. nephrolepis* (Trautv.) Maxim., *Pinus koraiensis*), rose (*Armeniaca mandshurica*, *Malus manshurica*, *Micromeles alnifolia*), elm (*Ulmus lacinata* (Trautv.) Mayr, *U. pumila* L.), and olive (*Fraxinus mandshurica*, F. *rhynchophylla*).

Low levels of lead were also observed in the leaves of *Kalopanax* septemlobus, Juglans mandshurica, Populus tremula, Acer barbinerve Maxim., *Celastrus flagellaris* Rupr., *Philadelphus schrenkii* Rupr. et Maxim., *Swida alba*.

This group includes almost all the forest-forming species of zonal coniferous–deciduous forests of the region studies. For it is noted the following pattern. If in the conditions of the local background such tree species typical of the region's natural forests as *Fraxinus mandshurica*, *F. rhynchophylla*, *Kalopanax septemlobus*, *Juglans mandshurica*, *Alnus hirsuta*, *Populus tremula*, and *Armeniaca mandshurica* according to the content of lead in assimilation organs correspond, in agreement with the accepted graduation, to the group of low maintenance, then, in the city stands, they belong to the reduced group, and *Betula platyphylla*, *B. davurica*, and *Ulmus pumila* L. belong to the elevated group, and *Abies holophylla* belongs even to the group with a high metal content. It is established that, in terms of urbanization and LEB, *Padus avium*, *Lonicera maackii*, *Deutzia amurensis*, and *Corylus heterophylla* are characterized by the highest powers of accumulation of lead. *Sambucus racemosa* and *Spiraea salicifolia* are at an elevated (close to the mean) content of Pb. Consistently low compared to the conditions, *Micromeles alnifolia*, *Malus manshurica*, *Quercus mongolica*, *Phellodendron amurense*, and *Ligustrina amurensis* are distinguished.

The average excess of lead in urban assimilation organs of plants (for a sample of 34 similar species presented representative of residential and parkland areas of the city) is 2.6 times. Above-background excess of the metal higher than the average is recorded in the leaves of *Populus tremula* (2.9), *Juglans mandshurica* (2.7), *Kalopanax septemlobus* (3.3), *Ulmus japonica* (3.3), *Alnus hirsute* (3.7), *Betula davurica* (3.8), and *B. platyphylla* (5.3 times). The maximum accumulation of lead is observed in the needles of *Abies holophylla* (6.6) and *Pinus koraiensis* (9.9), as well as in the leaves of *Ulmus pumila* (7.2) and *Armeniaca mandshurica* (12.5 times compared to LEB). The dominant in urban street plantings *Fraxinus mandshurica* concentrates lead 4.9 times more intensely; *Quercus mongolica*, predominant in suburban forests, 1.7 times.

Lead contents (mg/kg) in the leaves (needles) of plants of different families in urban (RZ) and local environmental background (PZ)

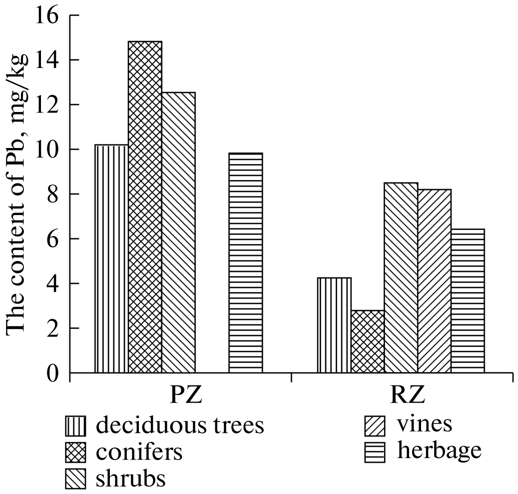
No.	Family	RZ				PZ			
		n	*M*	min	max	*n*	*M*	min	max
1	Aceraceae Juss.	5	7.18	1.24	12.45	4	4.52	3.23	5.80
2	Actinidiaceae Hutch.	–	–	–	–	3	8.95	8.11	10.30
3	Araliaceae Juss.	3	7.52	4.38	10.53	4	6.54	3.23	5.80
4	Berberidaceae Juss.	–	–	–	–	1	4.80	–	–
5	Betulaceae S.F. Gray	7	13.28	5.84	24.38	7	5.04	2.35	9.42
6	Bignoniaceae Rers.	1	8.03	–	–	–	–	–	–
7	Caprifoliaceae Juss.	5	12.91	9.43	18.22	8	8.78	5.84	14.60
8	Celastraceae Lindl.	4	12.76	8.78	16.56	5	8.69	1.09	12.07
9	Cornaceae Dumort.	1	11.71	–	–	1	2.36	–	–
10	Euphorbiaceae Juss.	–	–	–	–	1	7.90	–	–
11	Fabaceae Lindl. s. l.	4	7.55	5.14	11.54	2	4.65	3.99	4.37
12	Fagaceae Dumort.	1	8.98	–	–	1	5.31	–	–
13	Grossulariaceae Rers.	–	–	–	–	2	10.78	8.19	13.36
14	Hippocastanaceae Torr. et Gray	1	11.34	–	–	–	–	–	–
15	Hydrangeaceae Dumort.	2	18.85	17.77	19.94	3	7.20	1.26	12.03
16	Moraceae Lindl.	1	11.66	–	–	–	–	–	–
17	Juglandaceae A. Rich.	1	8.67	–	–	1	3.21	–	–
18	Oleaceae Hoffmgg. et Link	9	9.21	5.37	13.61	4	3.90	2.02	5.80
19	Pinaceae Lindl.	5	14.78	8.15	18.28	3	2.73	1.84	3.75
20	Rhamnaceae Juss.	–	–	–	–	1	13.23	–	–
21	Rhododendronoideae Drude	–	–	–	–	1	5.92	–	–
22	Rosaceae Juss.	16	13.88	5.95	25.67	13	6.93	0.81	15.06
23	Rutaceae Juss.	1	9.90	–	–	1	4.27	–	–
24	Salicaceae Mirb.	6	8.84	2.77	12.36	4	5.58	3.06	8.58
25	Shisandraceae Blume	–	–	–	–	1	8.85	–	–
26	Tiliaceae Juss.	2	10.76	10.59	10.92	3	4.70	3.99	5.82
27	Ulmaceae Mirb.	2	13.33	13.25	13.41	3	3.09	1.85	4.12
28	Vitaceae Juss.	–	–	–	–	1	12.36	–	–
	@@@	20	11.057	1.24	25.67	25	6.411	2.36	13.23

Note: *n*—number of species in the sample unit; *M*—arithmetic mean; min—minimum value; max– maximum value of the index.

Substantial variability in the accumulation of lead by assimilation organs of trees and shrubs is intrinsic to higher systematic ranks of plants (see table). In the RZ, the greatest extent of variation in lead content was found among species of the families Aceraceae (coefficient of variation of 60%), Betulaceae (51%), and Rosaceae (46%); in the PZ, Hydrangeaceae (76%), Betulaceae (61%), Rosaceae (56%), and Celastraceae (52%). The concentration of lead for the majority of families of urban vegetation is also significantly higher than background levels of the metal and increases in the following ranking order: Araliaceae (1.1 times higher than background); Celastraceae, Caprifoliaceae (1.5); Salicaceae, Aceraceae, Fabaceae (1.6); Fagaceae (1.7); Rosaceae (2.0); Tiliaceae, Rutaceae (2.3); Oleaceae (2.4); Hydrangeaceae, Betulaceae (2.6); Juglandaceae (2.7); Ulmaceae (4 3); Cornaceae (5.0); Pinaceae (5.4).

The high accumulation of lead by conifers in urban areas is due to a number of specific properties inherent in this group of plants. It is known that the life span of needles in natural conditions of growth is from 2–3 (*Pinus sylvestris*) to 8–10 (11) years (*Picea ajanensis* (Lindl. et Gord.) Fisch. ex Carr.) [27–29].

Although in urban conditions the life cycle of needles is significantly reduced, the accumulation of pollutants in conifers occurs within a period of a few years rather than in one growing season as in deciduous spe-



Lead content in plants of different biomes in residential and park zones of Vladivostok.

cies. In addition, the high assimilative surface of the needles and the specific biochemical and biophysical processes contribute to the high sorption of pollutant elements on the surface of the needles, followed by their involvement in the biological cycle.

The biological absorption coefficient, which characterizes the contribution of soil components to the total accumulation of chemical elements by plants, in the urban environment comes to an average of 0.19 for the sample and varies for different species from 0.05 to 0.54 (coefficient of variation of 50%). The recorded maximum values of the coefficient of biological absorption for a group of plants with high lead content in the leaves (needles) is up to 0.54 (*Padus maackii*). A regular decrease in BAC values was noted among the determined groups (high, moderately high, moderately low, and low levels of lead content in leaves and needles): 0.28 > 0.18 > 0.17 > 0.13, respectively.

In the background conditions this trend is preserved, but there is more intense absorption of soil lead by plant species belonging to the groups of high and moderately high lead content in the organs of assimilation. BAC decreases by groups of species as follows: 0.39 > 0.36 > 0.19 > 0.10. Its average value for the total sample of plants in these conditions is 0.24, the variability of species is 0.2–0.89, and the coefficient of variation is 66%.

A large contribution to the overall balance of elements in urban areas is made by the dust component. The dominant of urban trees—*Fraxinus mandshurica*, which grows mainly in ordinary roadside plantings—is the most prone to dust pollution, accounting for an average of 25% of the total metal content in the leaves. In general, in the samples (44 test areas), it varies in a very wide range: from 0 to 70%. For comparison, in the leaves of the dominant suburban forests *Quercus mongolica*, its share is on average 6% and varies depending on growing conditions from 0 to 21%.

Depending on the level of lead content in the analyzed fractions of urban vegetation (leaves and needles of woody plants, aboveground parts of herbs), the following series of life forms of plants can be built (see figure): herbaceous plants < deciduous trees < shrubs < conifers. In the environmental background, it takes the following form: coniferous trees < deciduous trees < grasses < shrubs < vines.

CONCLUSIONS

1. The present research has allowed us to estimate the accumulative ability for 128 species of vascular plants from 44 families and 82 genera. In the urban environment, the average content of Pb in the leaves (needles) of trees and shrubs is (11.50 ± 0.50) mg/kg with a variation from 1.24 (*Acer tegmentosum* Maxim.) to 25.67 mg/kg (*Crataegus pinnatifida*); in the local environmental background, respectively, (6.45 ± 0.49) mg/kg), 81 (*Armeniaca mandshurica*), and 15.06 mg/kg (*Rubus sachalinensis*). The metal content in the herbage of urban plant communities varies within 3.99–24.72, and for the forest park, it varies within 3.09–13.85 mg/kg with average values of (9.78 ± 0.44) and (6.46 ± 0.67) mg/kg, respectively.

2. The best lead concentration ability in urban conditions (14.07–25.67 mg/kg of air-dry matter) was shown by the moderately popular in Vladivostok *Padus maackii*, *Lonicera maackii*, *Microcerasus tomentosa*, *Philadelphus tenuifolius*, and *Weigela praecox*, as well as the rare in urban plantings *Crataegus pinnatifida*. A high sorption capacity for the given environmental pollutants (up to 13.61 mg/kg) was also found in *Ulmus japonica*, *U. pumila*, *Betula platyphylla*, and many introduced species *(Acer negundo*, *Populus alba*, *Morus alba*, *Aesculus hyppocastanum*, *Syringa vulgaris)*, including the widespread *Physocarpus opulifolia* and *Robinia pseudoacacia*. These species, especially tree species with large crowns and large green phytomass, particularly suit biological remediation of urban ecosystems.

Low accumulation of the metal (up to 10.53 mg/kg) characterizes the majority of typical species of coniferous–deciduous forests of the Far East, represented in the greening of Vladivostok (*Quercus mongolica*, *Fraxinus mandshurica*, *F. rhynchophylla*, *Kalopanax septemlobus*, *Phellodendron amurens*, *Juglans mandshurica*, *Alnus hirsuta*, *Populus koreana*, *Armeniaca mandshurica*, *Pyrus ussuriensis*, *Ligustrina amurensis*, etc.). Pb is poorly absorbed by the introduced species forming mostly inner street greening: *Forsythia suspensa*, *Catalpa bignonioides*, *Syringa oblata*, *Amorpha fruticosa*.

In the LEB conditions, the maximum accumulation of lead (up to 15.06 mg/kg) was recorded in a number of shrubs (most of the tested species *Euonymus*, *Corylus heterophylla*) and vines (*Actinidia kolo-*

mikta, *Vitis amurensis*). The main forest-forming species of suburban forests have low lead content in leaves and needles: 0.81–5.68 mg/kg air-dry matter.

3. Among the families having the best ability for lead accumulation observed in urban environments are Ulmaceae, Rosaceae, Pinaceae, and Hydrangeaceae; in natural background conditions, Caprifoliaceae, Shisandraceae, Actinidiaceae, Grossulariaceae, Vitaceae, and Rhamnaceae.

4. Urban vegetation is on average 2.6 times richer in lead than plants of LEB. The maximum excess metal content was recorded for *Abies holophylla* (6.6 times), *Pinus koraiensis* (9.9), *Ulmus pumila* (7.2) and *Armeniaca mandshurica* (12.5). An almost 5-fold excess of lead in the leaves was observed for the dominant of urban photosyntheses—*Fraxinus mandshurica*.

5. The phytoindicators of lead pollution in urban ecosystems in the regional conditions of the southern part of the Russian Far East should be the following types: *Padus maackii*, *Betula platyphylla*, *Ulmus japonica*, *Robinia pseudoacacia*, and *Physocarpus opulifolia*, which showed good sorption capacity and tolerant capabilities to Pb and are widespread in the urban landscape. To a lesser degree, those qualities are exhibited by *Fraxinus mandshurica*, *F. rhynchophylla*, *Ulmus pumila*, *Tilia amurensis*, and *Swida alba*.

The indication of soil pollution according to the preliminary data will best be performed by *Ulmus japonica*, *Betula platyphylla*, *Fraxinus pennsylvanica*, *Armeniaca mandshurica*, and *Physocarpus opulifolia*, meeting the necessary purposes of accumulation by assimilation organs and having other characteristics of phytoindicators.

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