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Ecological and Geochemical Classification of the Far Eastern Arboriflora

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Abstract—Materials have been generalized and a systematic analysis of the elemental composition of 110 species and 28 families of plants that form the tree–shrub tiers of forest phytocenoses, as well as the structure of urban landscaping in southern Primorye, has been performed in this article. A high differentiation of the species composition in the accumulative abilities to the weight of the metal, especially Zn and Mn, is found. The most stable parameters among the species are recorded for the Cu content. The species and families of high, low, and background content of heavy metals are distinguished based on the author's indicator, i.e., "the relative intensity of accumulation (RIA)" of chemical elements. A low content of heavy metals is more typical for the main arboriflora composition. At the same time, about half of the studied species accumulate some metals above background (average) values. The maximum content of metals, exceeding background values five times or more, is recorded in leaves (needles) of the concentrator species: Zn, *Salix udensis*, *Populus maximowiczii*, *P. nigra*, *P. tremula*, and *Syringa wolfii*; Mn, *Salix udensis*, *Sorbus pochuashanensis*, and *Picea* sp.; and Fe, *Crataegus pinnatifida*. A high heavy metal content the families is the most typical for Hydrangeaceae and Salicaceae; a low content is typical for Fabaceae, Pinaceae, Tiliaceae, and Aceraceae; and the background level is typical for Rosaceae. Based on the results, a phytogeochemical systematics of the main species and families of arboriflora has been developed for the first time for the vegetation of the Russian Far East.

Keywords: arboriflora, phytogeochemistry, heavy metals, ash content in the plants, geochemical ecology of plants, Primorsky krai

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Problems of species stability under conditions of ever-increasing anthropogenic pressure, as well as the transformation of anthropogenic environmental pollution by plants, have been of ongoing interest to the global scientific community over the past two centuries. Scientists working in the fields of biogeochemistry, geochemical ecology and geochemical plant ecology make a great contribution to solving these problems. Geochemical ecology, which emerged in the second half of the 20th century based on the biogeochemical teachings of V.I. Vernadsky, set the task of establishing the range of optimal values of geochemical environmental factors for the normal functioning of living organisms as a priority environmental problem (Kovalsky, 1974). When these limits are exceeded, pathological changes in organisms are formed as responses to environmental unfavorable conditions, often territorially expressed in the form of geochemical anomalies and biogeochemical endemias (Petrunina, 1974; Alekseeva-Popova, 1990; Kovalevsky, 1991; Petrunina et al., 1999). The geochemical ecology of plants, as one of the directions of geochemical ecology, considers the relationship between the plant and the environment mainly at the level of chemical interaction.

The content of chemical elements in plants depends on many factors, but the main ones are environmental parameters and species specificity of plants in terms of accumulation of elements, including those caused by their phylogeny in the past and evolution in the present (Kist, 1987; Bargagli, 2005; Alekseeva-Popova, 2013). Under conditions of the zonal natural (undisturbed) environment, background contents of chemical elements are reflected in plants. The geochemical background is a normalizing value in ecological and geochemical assessments. In azonal biogeochemical provinces and in zones of anthropogenic and technogenic impact, the anthropogenic component of the biogeochemical cycle plays a major role in the formation of the elemental composition of plants (Kovalsky, 2009; Alekseeva-Popova and Drozdova, 2013). In the latter case, it is very difficult to assess the contribution of natural and anthropogenic factors (Petrunina, 2003; Ufimtseva, 2015), especially since there is currently very little information on background indicators of soils and plants for most regions of the country.

Judging by the literature data, regional background soil indicators are currently being developed more actively than those for vegetation. There is, as a rule, only fragmentary information available in the literature regarding the latter. Unfortunately, systematic studies of the ecological and geochemical specificity of the richest and, in many respects unique, Far Eastern natural flora and vegetation have not been carried out so far. In our work we attempt to fill this scientific gap to some extent by using the example of the vegetation of the Muravyov-Amursky Peninsula, which geographically belongs to southern Primorye and has a rich composition of arboriflora characteristic of the southern Russian Far East.

When determining the ecological background as a methodological basis, the position was taken that the regional biogeochemical background of plants is formed mainly by the biogeochemical potential of edificator zonal plant biomorphs (Glazovskaya and Kasimov, 1987; Skarlygina-Ufimtseva, 1991). In forest ecosystems, this role is fulfilled by woody plants of flat interfluve (placor) phytocenoses.

It has been previously established (Shikhova, 2015, 2017) that the ecological and geochemical specificity of the forest ecosystems on the peninsula differs from that in other regions of Russia and the world by an increased content of Cd, Co, and decreased content of Mn in soils and plants. The higher concentrations of Pb and Zn were recorded in soils, while low levels of Zn were recorded in plants. It has also been shown that five metals, the content of which exceeds local background levels, are the priority anthropogenic pollutants of the urban vegetation in the city of Vladivostok. They form the following geochemical association of metal pollutants of urban plantations: $\{Fe_{4.1}Zn_{2.0}Pb_{1.9}Cu_{1.4}Ni_{1.3}\}$.

In previous studies, some specificity of the elemental chemical composition of certain plant biomorphs was also revealed (Shikhova, 2015). In particular, it was found that woody plants accumulate Mn more intensively than herbaceous plants: 1.5 times in forest communities and up to 2.5 times in urban landscaping. In urban conditions, tree species are also enriched with Cd by 1.8 times relative to herbaceous ones. In natural conditions, they insignificantly accumulate Co (1.4 times), but are poorer than herbaceous species in Ni and Fe (up to 1.5 times).

The main aim of the study was to identify the ecological and geochemical specificity of the Far Eastern arboriflora and differentiate its composition according to the intensity of the heavy metal accumulation at the level of the main taxa.

MATERIALS AND METHODS

The work was based on the actual data obtained as a result of long-term monitoring of landscaped areas in the city of Vladivostok and forest ecosystems of the Muravyov-Amursky Peninsula (Primorsky krai). The main objects of study in the forest territory of the peninsula (FT) were mainly plant communities dominated by or with a significant proportion of Mongolian oak (*Quercus mongolica* Fisch. ex Ledeb.) as the most common. Sampling was performed at 46 sampling plots (SPs) of 500 m^2 included in the monitoring system of soil and vegetation components of ecosystems. Forest plant communities of the peninsula served as a local ecological and geochemical background in assessing the state of urban green spaces in Vladivostok. Plant samples were taken in the residential area (RA) of the city at 135 SPs covering all types of urban green spaces such as row plantings, squares, old urban gardens, parks, intrablock landscaping, etc.

The assimilating organs of plants, leaves, and needles were taken for phytochemical analysis as indicators of annual accumulation of elements. At each sampling plot, a mixed plant sample was taken from 5–10 individuals of each species in the lower part of the crown of trees and the middle part of the crown of shrubs, if possible. The sampling was conducted after a 4–5 day rainless period, at the end of the growing season (before the beginning of leaf yellowing), corresponding to the time of maximum accumulation of elements. A total of 1250 phytosamples were taken for analysis.

The analytical preparation of samples and determination of heavy metal (HM) content in them were carried out in a certified laboratory by atomic absorption spectroscopy on a Shimadzu AA 6800 spectrophotometer in a hydrochloric acid solution of plant ash. The preliminary preparation of plant samples was carried out by dry ashing at 450°C. The analytical quality control of the work was carried out using blank samples and four calibration solutions. The content of eight metals was determined: Fe, Mn, Pb, Zn, Cu, Ni, Co, and Cd. The metals were chosen due to the technical capabilities of the analysis method we used. The concentrations of metals in plants were converted to dry weight and expressed in milligrams per kilogram of dry weight (mg/kg dry weight).

The material made it possible to estimate accumulative abilities to HMs in 78 species of trees, shrubs, and woody lianas forming tree and shrub tiers of natural phytocenoses of Muravyov-Amursky Peninsula, and 81 species of arboriflora (69 native and 12 introduced species) forming landscaping of the city of Vladivostok. The species collected for analysis represent 86% of the established total composition of the arboriflora of the forests of the Muravyov-Amursky Peninsula (Prokhorenko et al., 1996) and 70% of the species of trees and shrubs that form the urban landscaping of Vladivostok (Shikhova and Polyakova, 2006). As a result, heavy metal accumulation abilities were studied in 110 species of arboriflora (56 trees, 48 shrubs, and 6 woody lianas) belonging to 28 families and 63 genera. Fifty species and 17 families are common to the natural and urban flora. The names of plants in this work are given according to the eight-volume monograph (*Sosudistye*..., 1985–1996) with additions for the nonlocal flora by S.K. Cherepanov (1995) and I.Yu. Koropachinsky and T.N. Vstovskaya (2012).

For a comparative quantitative assessment of the intensity of metal accumulation by different systematic groups of plants, the coefficient of relative intensity of metal accumulation (RIA) was used. It represents the ratio of metal content in a particular species or plant family to their average (background) content in the sample and is expressed in relative units (RU). The average metal content in plants of natural forest ecosystems was taken as the local ecological background (LEB); in green areas of urban ecosystems it corresponded to the urban ecological background (UEB). Depending on the RIA value, three groups of plants were distinguished according to their ability to accumulate heavy metals: accumulation, dispersion, and background content. Group 1 includes species of weak (RIA ≥ 1.3), medium (RIA = 1.4–2.0), and high (RIA = 2.1–5.0) accumulation, as well as concentrator species (RIA > 5) of HMs; group 2 includes species of medium (RIA = 0.7–0.5) and high (RIA < 0. 5) dispersion of HMs, the content of metals in which is 1.4–2.0 and more than 2.0 times lower than background values, respectively; group 3 includes species with a background (RIA = 1.0) and similar (0.9 ≥ RIA ≥ 1.1) content of HMs.

The statistical processing of analytical data was performed using Microsoft Excel and Statistica 13.3 programs. When calculating the average metal content in the compared plant species, the sample size varied depending on the occurrence in the sampling plots from one to two individual samples of rare species to 60 samples of widespread species such as *Fraxinus mandshurica* Rupr. in urban plantations. Abnormally high contents qualified as "artifact" were excluded from the statistical processing of the samples, particularly from the calculation of medians. Such abnormal variants were found in Fe content in urban plantations, as well as Zn, Cu, and Mn in some species under natural and urban growing conditions.

RESULTS

The ash content in plants is an important biogeochemical indicator and is widely used in assessing the intensity of biological cycling of substances. It characterizes the share of participation of minerals in the structure of living matter and the ratio of its mineral and organic components. Ash content of assimilating organs of plants depends on many factors that are objective (taxonomic status, sampled organ, time and place of sampling, and ecological conditions of plant growth) and subjective (quality of sampling, their drying, methodically maintained ashing regime, etc.). To a certain extent, ash content reflects the adaptation of plants to growing conditions.

Ash Content in Leaves (Needles) of Plants and the Ability of Arboriflora Species to Accumulate HMs

The average ash content in leaves (needles) of the compared species of natural and urban arboriflora is presented in Table 1. The maximum ash content in natural forest communities was observed in *Ulmus laciniata* (Trautv.) Mayr (17.0%) and *Rubus sachalinensis* Lévl. (17.1%) and, in urban plantations, in *Acer tegmentosum* Maxim. (14.9%) and *Philadelphus tenuifolius* Ropr. et Maxim. (13.9%). Its minimum values were recorded in natural forests in the liana *Celastrus flagellaris* Rupr. (1.9%), as well as in the needles of *Pinus koraiensis* Siebold et Zucc. (2.7%) and in the leaves of *Berberis amurensis* Rupr. (5.2%), and *Acer pseudosieboldianum* (Pax) Kom. 5.8%); in urban landscaping, its minimum values were in the needles of *Pinus sylvestris* L. (4.2%), in leaves of *Salix caprea* L. (6.0%) and *Spiraea ussuriensis* Pojark. (6.7%).

The data presented in Table 1 also indicate a high degree of differentiation of the species composition of the Far Eastern arboriflora with respect to their ability to accumulate heavy metals. The maximum variability (87–109%) within the sample of species under comparison was observed for the content of Zn and Mn, while the most stable levels (22–35%) were recorded for Cu and Ni.

The generalizing analysis of the elemental composition of the flora showed that many of the examined species in both natural and urban habitats are characterized by increased accumulative ability for Zn and Mn. In the urban environment, this pattern is also preserved for Fe.

Among representatives of the forest arboriflora, the species concentrators of **Zn** were identified, the content of which in leaves exceeded background levels 13 times in *Salix gracilistyla* Miq. (218 mg/kg), 7 times in *S. udensis* Trautv. et Mey. (415 mg/kg), and 5 times in *Populus tremula* L. (160 mg/kg) and *Syringa wolfii* C.K. Schneid. (159 mg/kg). *Betula davurica* Pall. and *B. costata* Trautv. (up to 126 mg/kg), *B. platyphylla* Sukacz. (78 mg/kg), and *Salix caprea* (70 mg/kg) also accumulate zinc quite actively (up to 2–4 times higher than background values). Under urban conditions, species concentrators of Zn primarily include *Populus maximowiczii* A. Henry (440 mg/kg) and *P. nigra* L. (414 mg/kg), the content of zinc in which is seven times higher than UEB. Its high accumulation (2–3 times higher than background content) is also characteristic of other poplar species (*P. tremula* and *P. koreana* Rehd.), up to 197 mg/kg, birches (*Betula platyphylla*, *B. ermanii* Cham, and *B. davurica*) up to 205 mg/kg, and some species of willows (Salix *schwerinii* E. Wolf, *S. caprea*, and *S. alba* L.) up to 190 mg/kg, as well as *Crataegus pinnatifida* Bunge (146 mg/kg) and *Aralia elata* (Miq.) Seem. (127 mg/kg).

The willow *Salix udensis* was the most active **Mn** concentrator in natural forest communities: its leaves contain 1153 mg/kg of manganese, which is eight

Table 1. Background concentrations of heavy metals in leaves (needles) of arboriflora in natural forest (FT) and urban (RA) conditions

Heavy metals	Sampling site	Statistical parameters of heavy metal content			
		$M \pm m$	min	max	V, %
		(mg/kg of dry weight)			
Pb	FT	6.08 ± 0.42	0.34	17.48	61
	RA	11.37 ± 0.55	1.24	25.67	44
Ni	FT	2.07 ± 0.12	0.13	5.08	53
	RA	2.61 ± 0.09	0.50	4.56	31
Co	FT	1.42 ± 0.09	0.16	3.84	58
	RA	1.37 ± 0.06	0.27	3.08	39
Cd	FT	0.91 ± 0.07	0.07	2.71	71
	RA	0.95 ± 0.07	0.23	2.77	64
Zn	FT	32.8 ± 4.1	1.5	217.50	109
	RA	64.0 ± 5.1	19.1	204.50	70
Cu	FT	6.20 ± 0.24	0.79	12.65	34
	RA	8.56 ± 0.22	4.29	13.94	22
Mn	FT	149 ± 15	8	606	87
	RA	148 ± 15	31	662	87
Fe	FT	138 ± 5	20	260	35
	RA	565 ± 32	146	1430	50
Ash content	(% of dry weight)				
	FT	9.72 ± 0.34	1.86	17.05	30
	RA	10.03 ± 0.25	4.19	14.94	23

$M \pm m$, mean and standard error of the mean; min and max, limit contents.
V, coefficient of variation; FT, natural forest territory; and RA, residential area of the city.

times higher than LEB. This is followed by *Rhododendron mucronulatum* Turcz, *Syringa wolfii*, *Aralia elata*, *Salix gracilistyla*, and *Betula platyphylla*, in the leaves of which the Mn concentration ranges from 606 to 428 mg/kg. This is four to three times higher than the background level. Its values are slightly lower (up to 2–2.6 times higher than the background level) in *Corylus mandshurica* Maxim., *Quercus mongolica*, *Acer tegmentosum*, *Betula davurica*, *Ribes maximoviczianum* Kom., and *Carpinus cordata* Blume, ranging from 388 to 290 mg/kg. The best accumulative abilities to Mn in urban landscaping are found in the concentrator species *Sorbus pochuashanensis* (Hance) Hedl. (946 mg/kg) and *Picea pungens* Engelman. (f.) (888 mg/kg), metal reserves in assimilatory organs of which are six times higher than the urban background values. *Forsythia suspensa* Vahl., *Padus avium* Mill., *Corylus heterophylla* Fisch. et Trautv., *Acer tegmentosum*, *Pinus koraiensis*, and *Aralia elata* (from 662 to 428 mg/kg) also accumulate manganese up to four times higher than background values. In addition, a high Mn content, 296–385 mg/kg (up to 2.6 times higher than the background level), was recorded in *Betula platyphylla*, *Syringa wolfii*, and *Salix alba*.

The basic species of forest arboriflora in terms of **Fe** content are characterized by generally low values. An almost twofold excess of LEB relative to the background values was observed only in the leaves of *Rubus crataegifolius* Bunge and *Physocarpus amurensis* (Maxim.) Maxim., with an absolute value of 260 mg/kg. *Rubus sachalinensis*, *Eleutherococcus senticosus* (Rupr. et Maxim.) Maxim., *Betula davurica*, *Euonymus pauciflora* Maxim., *Carpinus cordata*, *Corylus heterophylla*, and *Spiraea ussuriensis* also accumulate iron up to 1.5 times higher than the background level (from 238 to 205 mg/kg). A somewhat different pattern in Fe accumulation is observed in representatives of the urban arboriflora. Iron is one of the main anthropogenic metal pollutants in the urban ecosystems of Vladivostok. Its average content in urban green spaces is four times higher than LEB (Shikhova, 2017). The most active concentrator species of Fe in this case is mountain hawthorn. The metal content in its leaves is 2975 mg/kg, which is 5 times higher than UEB and

22 times higher than LEB. *Padus maackii* (Rupr.) Kom., *Microcerasus tomentosa* (Trunb.) Eremin et Juschev, *Corylus heterophylla*, *Tilia taguetii* C.K. Schneid x *T. amurensis* Rupr., and *Ulmus japonica* (Rehd.) Sarg. accumulate iron up to 2.5 times higher than the urban background level, from 1430 to 1087 mg/kg.

The analytical data on the content of other HMs indicate their lower accumulation by plants and more stable content within the compared sample of species.

Among natural arboriflora, the highest **Pb** content, up to three times higher than LEB, was recorded in the leaves of *Rubus sachalinensis* (17.5 mg/kg), *Lonicera caerulea* L. (14,6 mg/kg), *Rhamnus davurica* Pall. (13.2 mg/kg), *Vitis amurensis* Rupr. (12.4 mg/kg), *Euonymus maximovicziana* Prokh. (12.1 mg/kg), and *Deutzia amurensis* (Regel) Airy Shaw (12.0 mg/kg). In representatives of the urban flora, the maximum Pb contents, up to 2 times higher than the UEB, were recorded in leaves of *Crataegus pinnatifida* (25.7 mg/kg), *Corylus heterophylla* (24.4 mg/kg), *Microcerasus tomentosa* (24.3 mg/kg), and *Cerasus sargentii* (Rehd.) Pojark. (21.7 mg/kg). All indicated Pb contents are about four times higher than the LEB.

Philadelphus schrenkii Rupr. et Maxim. (5.1 mg/kg), *Salix gracilistyla* (5.0 mg/kg), *S. udensis* (4.8 mg/kg), *Rubus sachalinensis* (4.5 mg/kg), and *Euonymus macroptera Rupr*. (4.3 mg/kg) are characterized by increased accumulative abilities to Ni in natural conditions, the metal content of which is 2.5 times higher than the local background level. Under the conditions of urban environment, the most significant Ni contents (1.6–1.7 times higher than the UEB) corresponding to average levels of HM accumulation were recorded in *Populus nigra* (4.6 mg/kg), *Picea pungens* (f.) and *Crataegus pinnatifida* (4.3 mg/kg), *Euonymus maackii* Rupr., and *Pinus koraiensis* (4.2 mg/kg).

The highest accumulation of **Co** was found in *Lonicera caerulea* (3.8 mg/kg), *Euonymus macroptera* (3.6 mg/kg), *Deutzia amurensis* (2.8 mg/kg), and *Philadelphus tenuifolius* (2.7 mg/kg) in forest ecosystems (2.0–2.7 times higher than the LEB) and in *Populus nigra* (3.1 mg/kg), *Crataegus pinnatifida* (2.6 mg/kg), and *C. maximowiczii* C.K. Schneid. (2.5 mg/kg) in urban conditions (2.0–2.2 times higher than the UEB).

The maximum content of **Cd** in natural conditions (2–3 times higher than the LEB) were found in leaves of *Salix udensis*, *S. gracilistyla* and *Lonicera caerulea* (2.7 mg/kg), and *Rubus sachalinensis* (2.6 mg/kg), as well as in *Euonymus maximovicziana* and *Rhamnus davurica* (1.8 mg/kg). In the urbanized environment, such excess was recorded in *Euonymus maackii* (2.8 mg/kg), *Eleutherococcus sessiliflorus* (Rupr. et Maxim.) S.Y. Hu (2.5 mg/kg), *Euonymus sacrosancta* Koidz. (2.4 mg/kg), and *Crataegus maximowiczii* (2.2 mg/kg), as well as in *Syringa vulgaris* L., *Euonymus macroptera*, *Deutzia amurensis*, and *Philadelphus tenuifolius* (2.1 mg/kg).

The highest **Cu** content was found in leaves of *Alnus hirsuta* (Spach) Fisch. ex Rupr. in forest phytocenoses, 24.4 mg/kg, which is 4 times higher than the LEB. In such conditions, woody lianas *Vitis amurensis*, *Actinidia arguta* (Siebold et Zucc.), and *Schisandra chinensis* (Turcz.) Baill., as well as *Salix udensis*, *S gracilistyla* (up to 10.6 mg/kg), and *Juglans mandshurica* Maxim. (9.1 mg/kg), accumulate copper up to 1.5–2.0 times higher than the background level. Among the species forming urban green spaces, similar accumulative abilities for copper were observed in *Euonymus maackii* (12.4 mg/kg), *Schisandra chinensis* (13.9 mg/kg), *Crataegus pinnatifida* (18.0 mg/kg), and *Syringa oblata* Lindl. (19.7 mg/kg).

Species with Low HM Content in Leaves (Needles) of Plants

Species conditionally called metal disperser species are characterized by a HM content 1.3–2 and more times lower than the sample average (RIA < 1.0). This group of species is the most numerous. In natural phytocenoses, it includes primarily six species in which the value of all eight analyzed HMs corresponds to the low content status: *Celastrus flagellaris*, *Pinus koraiensis*, *Armeniaca mandshurica* (Maxim.) B. Skvortz., *Malus manshurica* (Maxim.) Kom., *Padus maximowiczii* (Rupr.) Sokolov, and *Abies holophylla* Maxim. Another eight species of natural arboriflora disperse seven HMs: all HMs except for Cu, *Acer mandshuricum* Maxim., *Maackia amurensis* Rupr. et Maxim., *Salix caprea*, and *Ulmus pumila* L.; except for Zn, *Juglans mandshurica*, *Ulmus laciniata*, and *Cerasus sargentii*; and except for Co, *Tilia amurensis* Rupr. A low content of six HMs is recorded in *Kalopanax septemlobus* (Thunb.) Koidz. (all HMs except for Zn and Mn), *Acer barbinerve* Maxim. and *Berberis amurensis* (except for Cu and Mn), and *Fraxinus mandshurica* and *Micromeles alnifolia* (Siebold et Zucc.) Koehne (except for Cu and Fe). The minimum contents of Cd (0.07 mg/kg), Ni (0.13 mg/kg), Co (0.16 mg/kg), and Pb (0.34 mg/kg) were recorded in the needles of *Pinus koraiensis*, and Zn (1.53 mg/kg), Cu (0.79 mg/kg), Fe (20 mg/kg), and ash content (1.86%) were recorded in the leaves of *Celastrus flagellaris* and Mn (7.7 mg/kg) in *Maackia amurensis*. Amur maakia is also characterized by very low accumulation of Ni (0.22 mg/kg), Co (0.27 mg/kg), Cd (0.11 mg/kg), and Pb (1.35 mg/kg). In addition to the mentioned minimum values of four HMs, a very low content of Mn (10 mg/kg) was detected in *Celastrus flagellaris* and of Cu (1.44 mg/kg) in Korean pine (Korean cedar). These three species in forest ecosystems of the study region are the most typical representatives of the group of low-HM species. They are represented sporadically and need further more detailed studies for final conclusions.

Micromeles alnifolia and *Spiraea ussuriensis* are at the top of the group of typical HM disperser species in urban landscaping. The content of all analyzed metals in them is lower than the UEB: in *Micromeles alnifolia*, from 1.3 times for Co (1.1 mg/kg) to 4.7 times for Mn (31 mg/kg), and in *Spiraea ussuriensis*, from 1.2 times for Cd (0.7 mg/kg) to 5.1 times for Co (0.3 mg/kg). The low accumulation of seven HMs was observed in *Fraxinus pennsylvanica* Marsh., *Amorpha fruticosa* L., and *Lespedeza bicolor* Turcz. of all HMs except for Cu; in *Aesculus hyppocastanum* L., except for Pb; and in *Carpinus cordata*, except for Mn. Another five species are characterized by low contents of six HMs: *Alnus hirsuta* (all HMs, except for Pb and Cu), *Catalpa bignonioides* Walt. (except for Co and Cu), *Corylus mandshurica* (except for Mn and Cd), and *Acer tegmentosum* and *Maackia amurensis* (except for Mn and Cu). A low content of some of metals, 1.5 or more times lower than the background values, was recorded in 26 more species found only in the RA (mainly introduced species). The minimum HM contents in the sample of urban arboriflora were recorded in the following species: *Acer tegmentosum*, Pb (1.24 mg/kg) and Ni (0.50 mg/kg); *Spiraea ussuriensis*, Co (0.27 mg/kg); *Micromeles alnifolia*, Mn (31 mg/kg); *Maackia amurensis*, Cd (0.23 mg/kg); *Populus maximowiczii*, Fe (146 mg/kg); *Corylus mandshurica*, Zn (19.1 mg/kg); and *Pinus sylvestris*, Cu (4.3 mg/kg). The indicated metal contents are from nine (Pb) to five (Ni, Co, Mn), four (Cd, Fe), three (Zn), and two (Cu) times lower than UEB levels.

Species with Background HM Content

Approximately half of the species in natural (48%) and urban (54%) plant communities have background levels of metals.

In forest ecosystems, 15 out of 39 species belonging to the group of background indicators are found only in natural phytocenoses. The absolute majority of representatives of this group are characterized by the background content of one to two TMs (mainly Cu, Zn, and Ni). The exceptions are *Sorbaria sorbifolia*, whose leaves have a close to background content of six HMs (all HMs except Pb and Co); *Rhododendron mucronulatum* with a background content of four HMs (Pb, Co, Cd, and Zn); and three HMs each were recorded in *Viburnum sargentii* Koehne (Pb, Ni, and Cu) and *Rubus crataegifolius* (Co, Cu, and Mn).

With a softer approach, which includes contents close to the background level (near background content), the composition of the group almost doubles.

In urban conditions, most of the considered group of species (34) are characterized by the background content of one HM, 9 are characterized species by two HMs (mainly Fe, Pb, Co, and Cu in different combinations), and only 2 species have a content of three HMs close to the UEB: *Sambucus racemosa* (Pb, Cd, and Cu) and *Tilia amurensis* (Ni, Cu, and Fe). The largest number of species with the background value was recorded for Fe (11 species), Pb, and Co (9 species each), and Cu (8 species). The abundance of the group increases 1.6 times when species with the HM content close to the background level are taken into account.

Differentiation of Arboriflora Families in Terms of HM Accumulation Intensity

The composition of the studied arboriflora is represented by 28 families, of which 17 are common for the compared growing conditions. Additionally, the list of families of the forest arboriflora includes seven families and the list of the urban arboriflora includes four monospecific families of introduced species. Rosaceae Juss. is the most numerous family, represented by 13 species in the FT and 16 species in the RA. After that are the family Betulaceae S.F. Gray, seven species in both localities; Caprifoliaceae Juss., eight species in the FT and five in the RA; and Aceraceae Juss. and Celastraceae Lindl., five species each everywhere. The numerous families in the RA also include Oleaceae Hoffmgg. et Link, nine species (FT, four species); Salicaceae Mirb., seven species (FT, four species); and Pinaceae Lindl., five species (FT, three species). The statistical analysis of the data showed that the highest variability of HMs among the families was observed in the content of Cd and Mn: in the FT, 54 and 84%, and in the RA, 62 and 52%, respectively. Meanwhile, the Cd content in the FT varies from 0.14 (Juglandaceae A. Rich.) to 1.82 mg/kg (Rhamnaceae Juss.) and in the RA from 0.30 (Pinaceae) to 2.24 mg/kg (Celastraceae). Salicaceae, Grossulariaceae Rers., Euphorbiaceae Juss., and Actinidiaceae Hutch. also belong to families with high Cd content (1.5–2 times higher than average values) in the FT (1.37–1.73 mg/kg) and Cornaceae Dumort. (1.53 mg/kg) in the RA. Low Cd contents (two to three times lower than the average values (0.27–0.40 mg/kg)) were recorded, regardless of growing conditions, in the families Pinaceae, Tiliaceae Juss., Fabaceae Lindl. s. l., and Fagaceae Dumont.; in the RA they were in the families Bignoniaceae Rers. (0.36 mg/kg) and Hippocastanaceae Torr. et Gray (0.44 mg/kg) and, in the FT, in the family Ulmaceae Mirb. (0.38 mg/kg).

The Mn content in plants in the FT ranges from 43–606 mg/kg (Ulmaceae and Ericaceae Juss., respectively), while in the RA it ranges from 33–381 mg/kg (Bignoniaceae and Pinaceae, respectively). Mn is actively accumulated (2–3 times higher than the average values) by species of the families Betulaceae (FT, 290 mg/kg, RA, 223 mg/kg), as well as Salicaceae (460 mg/kg) and Fagaceae (315 mg/kg) in the FT and Aceraceae (210 mg/kg) in the RA. Among the common families of different habitats, the minimum Mn accumulation (47–65 mg/kg) was recorded in Rutaceae Juss. and Celastraceae. In the forest communities, plants of the families Berberidaceae Juss., Juglandaceae, Rhamnaceae, Actinidiaceae, Euphorbiaceae, and Vitaceae Juss. also weakly accumulate the metal

(54–82 mg/kg) and, in urban conditions, Bignoniaceae (33 mg/kg) and Cornaceae (61 mg/kg).

Among other HMs, a significant excess of the average values (from two times and more) was recorded only in Zn accumulation: Salicaceae, 215 mg/kg in the FT and 242 mg/kg in the RA; Betulaceae, 62 mg/kg in the FT and 102 mg/kg in the RA; and Oleaceae, 59 mg/kg in the FT. The other metals are more characterized by 1.5 to 2-fold accumulation relative to the background levels. Such concentrations were recorded in the FT for Pb in plants of the families Rhamnaceae, Vitaceae, and Grossulariaceae (9.9–13.2 mg/kg); for Co in the family Rhamnaceae (2.53 mg/kg); for Ni in the family Hydrangeaceae Dumort. (3.52 mg/kg); and for Cu in the family Vitaceae (12.6 mg/kg). In the RA, similar Pb contents were recorded in the family Hydrangeaceae (19.6 mg/kg), Zn in Pinaceae (71 mg/kg) and Ulmaceae (79 mg/kg), Cu in Schisandraceae Blume (13.9 mg/kg), and Fe in Ulmaceae (993 mg/kg) and Tiliaceae (802 mg/kg).

However, most families of the Far Eastern arboriflora, like its species composition, are characterized by lower contents of metals up to two to three and more times relative to the background values. In the FT, these families include Fabaceae according to the content of Pb (2.9 mg/kg) and Co (0.62 mg/kg); Pinaceae, Pb (1.8 mg/kg); and Tiliaceae, Co (0.54 mg/kg). In the RA, they include Rutaceae according to the content of Zn (24 mg/kg) and Fabaceae according to Fe (364 mg/kg).

The analysis of ash content of the family spectrum of the arboriflora also allowed us to note some regularity in its content. Thus, different families but with close values are at the top of the compared lists in relation to the series of ash content: Rhamnaceae (15.1%) in the forest zone and Moraceae Lindl. (14.9%) in the urban zone. High ash contents were also recorded in plants of the families Hydrangeaceae and Ulmaceae, from 13.2 to 14.2%. In natural conditions, an increased ash content in leaves was recorded also in lianas of the families Actinidiaceae (12.8% and Vitaceae (11.6%), as well as in shrubs of the families Actinidiaceae (12.8%) and Vitaceae (11.6%) and in shrubs of the family Grossulariaceae (11.7%); in urban plantations, they were recorded in leaves of trees of monospecific families Rutaceae (13.1%), Cornaceae (11.9%), and Hippocastanaceae (11.6%), as well as in shrubs of the genus *Euonymus* L. (10.8–12.5%) belonging to the family Celastraceae.

A low ash content regardless of growing conditions is characteristic of the families Fabaceae, Fagaceae, Betulaceae, and Tiliaceae (6.5–8.8%), and the minimum ash content is characteristic of the family Pinaceae (4.2% in the FT and 5.9% in the RA). The data for the families Rosaceae and Salicaceae are similar to the values of the average ash content: 10.1 and 9.3% in the FT and 10.5 and 10.2% in the RA, respectively.

It has been also stated that the ash content in leaves and needles of plants of the families Pinaceae, Aceraceae, and Shisandraceae Blume in urban plantations is slightly higher (up to 1.4 times) when compared with families of the same name of the forest phytocenoses. A similar but less pronounced pattern is characteristic of the families Juglandaceae (1.3 times), as well as Fabaceae and Rutaceae (1.2 times). Most likely, it is caused by higher dustiness of their leaves.

The cluster analysis of plant family spectra was performed in order to find the common ecological and geochemical regularities in the accumulation of the complex of the considered metals by plants. The figures show dendrograms of the families of the residential (Fig. 1) and forest (Fig. 2) areas of the study region. Judging by the data, urban plants are characterized by less strong relationships and significant fragmentation of the family spectrum. Among their total composition, a cluster of nine families with a core of Celastraceae–Moraceae–Hippocastanaceae–Cornaceae–Rutaceae–Bignoniaceae, as well as several small groups of two-three families, are separated. Unlike them, two clusters of families are clearly distinguished among the plants of forest communities. The first cluster is quite dense and numerous, comprising 13 families. The closest relationships are found between the families Celastraceae–Rhamnaceae–Vitaceae–Euphorbiaceae–Actinidiaceae–Fabaceae, as well as Berberidaceae–Ulmaceae–Rutaceae–Juglandaceae and Caprifoliaceae–Rosaceae–Hydrangeaceae. The second cluster is smaller in a number with a core of the families Aceraceae–Tiliaceae–Araliaceae–Shisandraceae. According to the data, close patterns in the accumulation of metal complexes, regardless of growing conditions, are found for the families Caprifoliaceae and Rosaceae, and less clearly expressed patterns are found for the families Celastraceae and Rutaceae.

DISCUSSION

A general analysis of the materials showed that 64% of the composition of natural arboriflora and 58% of the composition of urban arboriflora accumulate HMs in leaves (needles) up to 1.5 times and more relative to the background levels. This characterizes them as species of medium to high ability for HM accumulation. Of them, 1/3 of the species composition in the FT and 1/4 in the RA accumulate three to four metals each, while the rest species accumulate one to two metals each. The exceptions are four species accumulating from five to seven HMs: *Salix gracilistyla* (Ni, Co, Cd, Zn, Cu, and Mn) and *S. udensis* (Ni, Cd, Zn, Cu, and Mn) in forest plant communities and *Crataegus pinnatifida* (Pb, Ni, Co, Cd, Cu, Zn, and Fe) and *Euonymus maackii* (Pb, Ni, Co, Cd, and Cu) in urban plantations.

The maximum abilities to concentrate HMs among natural arboriflora were found in *Salix uden-*

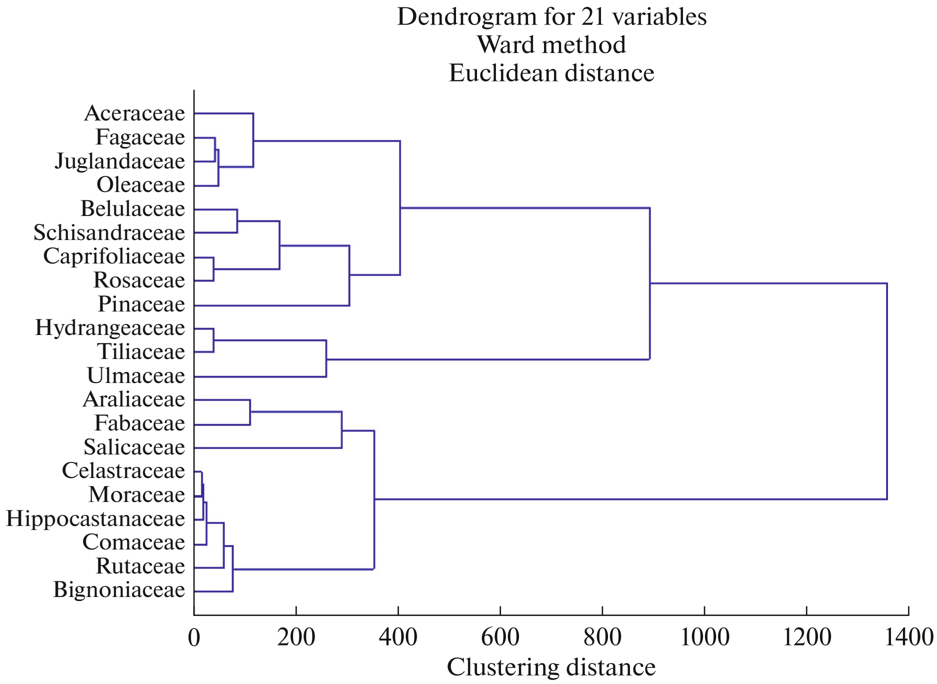

Fig. 1. Dendrogram of plant families forming green areas of the city of Vladivostok, derived from a cluster analysis of elemental chemical composition of plants.

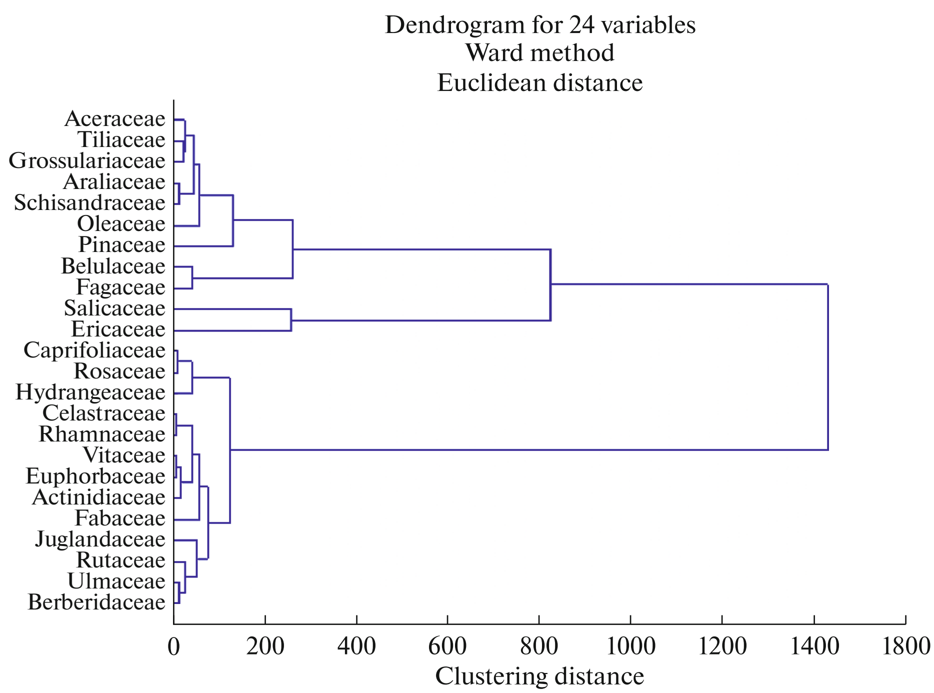

Fig. 2. Dendrogram of plant families forming forest ecosystems of the Muravyov-Amursky Peninsula derived from cluster analysis of elemental chemical composition of plants.

sis, in which leaves with almost 13-fold concentration of Zn (415 mg/kg) and 8-fold concentration of Mn (1153 mg/kg) relative to FEB were recorded. Unfortunately, there is very little information in the scientific literature concerning regional vegetation clarks, but according to the available data on the plants of the forest-steppe and steppe Volga region, the species of the family Salicaceae and the genus *Populus* L. are indicated as the main concentrators of Zn (Prokhorova et al., 1998). The Mn content in leaves of trees in this region varies from 5.7 mg/kg (*Viburnum opulus* L.) to 610.0 mg/kg (*Padus avium*) and Zn from 7.08 mg/kg (*V. opulus*) to 24.39 mg/kg (*Malus sylvestris* (L.) Mill.) (Prokhorova, 2004). The following average contents of metals are reported in the literature for plants of unpolluted soils of Novosibirsk oblast: Mn, 104.8 mg/kg; Zn, 58.3 mg/kg (Ilyin, 1991). However, if we compare our data with the literature data on hyperaccumulator species of Zn and Mn accumulating more than 10000 mg/kg of metals in leaves (Brooks, 1998; Krämer, 2010), we can see that they are more than an order of magnitude less than the indicated maximum. Among Zn hyperaccumulators, many species of the family Brassicaceae Burnett were found. Brassicaceae Burnett. (Petrunina, 1974; Baker and Brooks, 1989) with very high concentrations of Zn, but the absolute maximum of Zn (51600 mg/kg) was recorded in the aboveground dry mass of *Thlaspi caerulescens* J. Presl et C. Presl. Presl (Brown et al., 1994). According to the literature sources, the tree *Macadamia neurophylla* F. Muell. in Australia is the most active Mn hyperaccumulator; leaves contain 51800 mg/kg of the metal (Baker and Walker, 1990).

Among urban arboriflora, HM concentrator species include poplars (*Populus nigra*, and *P. maximowiczii*) with sevenfold excess of UEB for Zn (441 and 414 mg/kg, respectively), as well as *Sorbus pochuashanensis* and *Picea pungens* (f.) with sixfold enrichment of Mn (888 and 946 mg/kg, respectively) and *Crataegus pinnatifida* with fivefold enrichment of Fe (2975 mg/kg). It should be noted that, although Mn concentrations are 11 times and Zn concentrations are 23 times lower than those reported in the literature for plants belonging to hyperaccumulators of these metals (Baker and Brooks, 1989), they are up to 2–4 times higher than the excess, or toxic, limits of metal concentrations in mature leaf tissues (Kabata-Pendias and Pendias, 1989). According to the authors' data, they are 100–400 mg/kg for Zn and 300–500 mg/kg for Mn. However, it should be noted that the above toxic concentrations of metals are summarized by the authors mainly based on the materials for herbaceous plants, and can be, in our opinion, only as indicative criteria for the assessment of woody plants, especially in the accumulation of Mn, the content of which in woody species, judging by our data (Shikhova, 2017), significantly (up to 1.5 times and more) exceeds herbaceous species.

In our earlier literature review on metal accumulation by plants in green spaces of Russian cities and neighboring countries (Shikhova, 2022), there is information on the content of Zn and Mn in plants of different regions. The highest Mn values are reported in leaves of *Betula pendula* Roth. in plantations of the city of Vitebsk (Belarus), 1080 mg/kg (Vadkovskaya and Gurch, 1999), and *Tilia cordata* Mill. in green spaces of the city of Kaliningrad, 810 mg/kg (Maslennikov et al., 2015); the highest values of Zn were found in leaves of *Betula pendula* in landscaping of the city of Irkutsk, 650 mg/kg (Shergina and Mikhailova, 2007). These literature data are similar to those obtained by us for Mn content, but about 1.5 times higher than Zn concentrations.

A comparison of the ability of common species to accumulate HMs in natural and urban environments indicates that 36 out of 50 species accumulate some metals to varying degrees. The list of these species and their HM content are presented in Table 2. According to the data, the most active concentrators of the sum of metals are *Corylus heterophylla*, accumulating Pb, Cd, Mn, and Fe and *Syringa wolfii*, accumulating Ni, Zn, Cu, and Mn. Lilacs in urban plantings are also enriched with Fe. Judging by the final results, the ability to accumulate Mn and Cd was shown by eight species; Zn by six species; Pb by three species; Ni, Cu, and Fe by two species; and Co by one species.

Also noteworthy is the fact that the absolute majority of the studied species is more characterized by a low (below background values) content of at least one metal, which may indirectly indicate the presence of barrier mechanisms in the absorption of metals in a considerable number in the arboriflora plants. In the FT, only *Rhododendron mucronulatum* and *Sorbaria sorbifolia* are exceptions to this rule; in the RA, they are *Corylus heterophylla*, *Syringa wolfii*, and *Microcerasus tomentosa*, the content of HMs in which is higher or close to the background values. The minimum contents of all HMs were recorded in plants of forest phytocenoses: Cd (0.07 mg/kg), Ni (0.13 mg/kg), Co (0.16 mg/kg), and Pb (0. 34 mg/kg) in needles of *Pinus koraiensis*; Cu (0.79 mg/kg), Zn (1.53 mg/kg), and Fe (20 mg/kg) in leaves of *Celastrus flagellaris*; and Mn (7.7 mg/kg) in leaves of *Malus manshurica*. They are from 2 (Co) to 7 (Zn) and 12 (Mn) times lower than the minimum values recorded in plants of urban plantations. *Maackia amurensis* and *Micromeles alnifolia* are typical metal dispersers among the same-name species of urban and natural plantations. They are distinguished by a low content of Pb, Ni, Cd, and Zn; tje Amur maakia also has low content of Co and Fe, and dead-headed mountain ash has a low content of Mn. A low content of one to two HMs, mainly Mn, Cd, and Zn, was established for other common species.

The group of species with background HM contents is the smallest. *Sorbaria sorbifolia* with a background content of five HMs (Ni, Zn, Cu, Mn, and Fe) and *Rhododendron mucronulatum* containing three HMs (Pb, Co, and Cd) of background level are their most typical representatives in forest phytocenoses. In urban plantations, three species such as *Acer ginnala* (Zn, Cu, and Fe), *Sambucus racemosa* (Pb, Cd, and Cu), and *Tilia amurensis* (Ni, Mn, and Fe) lead the group of the species with the background content. The other species, both in forest and urban conditions, are characterized by the background content of one or

Table 2. List of species with high content of heavy metals in leaves (needles)

Plant species	Content of heavy metals (mg/kg of dry weight)															
	Pb		Ni		Co		Cd		Zn		Cu		Mn		Fe	
	RA	FT	RA	FT	RA	FT	RA	FT	RA	FT	RA	FT	RA	FT	RA	FT
Corylus heterophylla	**24.4**	9.4	–	–	–	–	1.39	1.53	–	–	–	–	**519**	209	**1355**	205
Syringa wolfii	–	–	3.99	2.90	–	–	–	–	111	**159***	12.0	8.7	**313**	**586**	847	–
Aralia elata	–	–	–	–	–	–	–	–	127	48	–	–	**428**	**500**	–	–
Betula davurica	–	–	–	–	2.28	–	–	–	**167**	**126**	–	–	254	**307**	–	218
Betula platyphylla	–	–	–	–	–	–	–	–	**205**	**78**	–	–	**385**	**428**	–	–
Lonicera maackii	18.2	10.0	–	3.44	–	2.14	1.52	1.75	–	–	–	–	–	–	792	–
Deutzia amurensis	19.9	12.0	–	2.81	–	2.86	**2.08**	1.68	–	–	–	–	–	–	–	–
Padus avium	–	10.7	3.64	3.20	–	2.08		1.40	–	–	–	–	**575**	–	–	–
Euonymus macroptera	–	11.4	–	**4.26**	–	**3.62**	**2.10**	1.28	–	–	–	–	–	–	–	–
Corylus mandshurica	–	8.4	–	–	–	–	1.31	1.35	–	–	–	–	–	**388**	–	–
Eleutherococcus senticosus	–	9.5	–	–	–	–	**2.53**	1.59	–	–	–	–	–	–	–	220
Eleutherococcus sessiliflorus	–	10.2	–	–	1.96	2.19	–	1.62	–	–	–	–	–	–	–	–
Philadelphus tenuifolius	19.2	–	–	–	2.16	–	–	–	–	–	–	–	–	–	934	199
Populus tremula	–	–	–	–	–	–	–	1.28	**197**	**160***	–	–	–	216	–	–
Schisandra chinensis	–	8.8	–	–	–	–	–	–	–	–	13.9	9.3	–	215	–	–
Acer mono	–	–	–	–	–	–	–	1.31	–	–	–	–	251	238	–	–
Acer pseudosieboldianum	–	–	–	–	–	–	–	–	–	–	–	8.6	227	270	–	–
Euonymus sacrosancta	–	9.5	–	–	–	–	**2.30**	1.43	–	–	–	–	–	–	–	–
Lonicera praeflorens	–	–	–	–	–	–	1.28	1.32	–	–	–	–	–	–	–	186
Acer tegmentosum	–	–	–	–	–	–	–	–	–	–	–	–	**518**	**311**	–	–
Salix caprea	–	–	–	–	–	–	–	–	**147**	**70**	–	–	–	–	–	–
Carpinus cordata	–	–	–	2.96	–	2.03	–	–	–	–	–	–	–	290	–	212
Quercus mongolica	–	–	–	2.86	–	–	–	–	–	–	–	8.9	–	**315**	–	–
Alnus hirsuta	–	–	–	–	–	–	–	–	–	–	–	**24.4**	–	204	–	–
Fraxinus rhynchophylla	–	–	–	3.19	–	2.14	–	–	–	–	–	–	–	–	–	–
Spiraea ussuriensis	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	205
Juglans mandshurica	–	–	–	–	–	–	–	–	–	–	–	9.1	–	–	–	–
Crataegus maximowiczii	19.2	–	3.61	–	2.50	–	**2.20**	–	–	–	–	–	–	–	779	–
Pinus koraiensis	18.3	–	4.10	–	–	–	–	–	99	–	–	–	**461**	–	–	–
Cerasus sargentii	21.7	–	–	–	–	–	1.30	–	–	–	–	–	–	–	916	–
Padus maackii	20.0	–	–	–	–	–	–	–	–	–	–	–	–	–	**1430**	–
Ulmus pumila	–	–	–	–	–	–	1.42	–	–	–	–	–	–	–	898	–
Viburnum sargentii	–	–	–	–	–	–	1.60	–	–	–	–	–	–	–	–	–
Ulmus japonica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1087	–
Euonymus pauciflora	16.6	–	–	–	–	–	1.76	–	–	–	–	–	–	–	–	217
Tilia taguetii × *T. amurensis*	17.8	–	–	–	–	–	–	–	–	–	–	–	–	260	**1187**	–

RA, residential area; FT, natural forest territory; HM concentrations exceeding the ecological background by 1.4–2.0 times are in bold, 3–4 times are framed, and 5 times and more are framed and marked with an asterisk.

(rarely) two metals. Background HM contents were recorded in 12 species among the same-named species in forest and urban habitats, but only three of them were identical in both conditions. Thus, *Sorbaria sorbifolia* and *Lespedeza bicolor* are characterized by the background content of Cu, and *Sambucus racemosa* is characterized by the background content of Cd. However, in addition, the background content of Ni, Zn, Mn, and Fe was found in Ural false spirea in the FT and Co in the RA; in shrub lespedeza, Ni in the FT; and in European red elderberry, Pb and Cu in the RA. The background values of Cu and Fe are common for most species of this group; in the RA, they are supplemented by Co and Pb.

The final analysis of elemental composition of leaves (needles) of the same-named species growing in forest phytocenoses and urban plantations is presented in Table 3. According to the data, 16 species are characterized by high abilities to accumulate HMs. Five species are typical representatives of this group of plants: *Corylus heterophylla* (Pb, Cd, and Fe), *Eleutherococcus sessiliflorus* (Cd), *Populus tremula* (Zn), *Acer mono*, and *Syringa wolfii* (Mn). The group of the background HM content is represented by five species. They are characterized by the background content of any one metal: *Acer pseudosieboldianum* and *Ligustrina amurensis* Rupr., Zn; *Lespedeza bicolor*, Cu, *Sorbaria sorbifolia*, Co; and *Sambucus racemosa*, Cd. The group of species of low HM content is the most numerous. It is formed predominantly by species of weak accumulation of one to two HMs, mainly Cd, Zn, and Mn. Some species disperse three to five HMs: *Maackia amurensis* (Co, Cd, and Fe), *Malus mandshurica* (Zn, Mn, and Fe), *Fraxinus mandshurica* and *Armeniaca mandshurica* (Cd, Zn, and Mn), *Abies holophylla* (Ni, Co, and Cd), *Salix caprea* (Pb, Co, Mn, and Fe), *Micromeles alnifolia* (Pb, Ni, Cd, Zn, and Mn).

In general, the main composition of arboriflora is more characterized by the differentiated accumulation of HMs, when plants accumulate some metals and are indifferent to others. For example, a high content of Mn, background content of Zn, and low content of Cd was recorded in the leaves of *Acer pseudosieboldianum*. Low contents of Pb, Co, Mn, and Fe with a simultaneously high concentration of Zn were found in the leaves of *Salix caprea*. *Aralia elata*, *Betula davurica*, and *B. platyphylla* intensively accumulate Zn and Mn, but at the same time *Aralia elata* disperses Pb and birch trees disperse Cd. *Deutzia amurensis* and *Lonicera maackii* (Rupr.) Herd. are active in accumulation of Pb and Cd, but indifferent to Mn, etc.

The generalized materials on the HM and ash contents in the studied plants of the families of arboriflora are presented in Table 3. According to the data, 11 families are able to accumulate HMs at a high level. First of and foremost, these are the families Hydrangeaceae (accumulate Ni, Co, Cd, and Fe) and Salicaceae (accumulate Ni, Cd, and Zn). Plants of the family Hydrangeaceae in urban conditions also accumulate Pb and Cu (Pb very significantly, almost twice as much relative to the UEB). The abilities to concentrate HMs were found in the plants of the family Salicaceae in relation to Zn. Its content in plants of urban plantations is five times, and in natural phytocenoses up to eight times higher than background values. Most of plant families in the analyzed sample are characterized by the accumulation of one to two metals.

A low content of HMs (from 1.3 to 6 times below background levels) was found in 15 families. Families Fabaceae (low content of Pb, Co, Cd, and Fe), Pinaceae (Co, Cd, and Cu), and Tiliaceae (Co, Cd, and Zn) are their most typical representatives. A common feature of these families is the weak accumulation of Co and Cd. The dispersion of HMs is more pronounced under local background conditions. The other families of this group are characterized by weak accumulation of any one metal. It is also interesting to note that the minimum content of the most aggressive environmental pollutants, Pb and Cd was recorded in the family Juglandaceae (1.1 and 0.14 mg/kg, respectively) in the FT and the minimum content of Pb in the family Schisandraceae (6.7 mg/kg) and Cd in the family Pinaceae (0.30 mg/kg) in the RA.

The group of the background HM content is represented by ten families. Half of them are characterized by background content of two to three HMs: Aceraceae (Zn, Cu, and Fe), Araliaceae Juss. (Ni and Co), Betulaceae (Ni and Cu), Rosaceae (Ni and Cd), Tiliaceae (Cu and Mn), and the other families are characterized by the background content of any one metal: Rutaceae, Pb; Oleaceae, Co; Salicaceae, Cu; and Fabaceae and Hydrangeaceae, Zn. It is interesting to note that the multispecies family Rosaceae corresponds most closely to a typical representative of this group. In urban plantations, the background contents of Ni, Co, Cd, Zn, Cu, and Mn were recorded in Rosaceae, while in forest communities, the background contents of Pb, Ni, Cd, and Fe were recorded.

CONCLUSIONS

An ecological and geochemical assessment of the basic composition of arboriflora of southern Primorye showed high differentiation of species in accumulative abilities to heavy metals. The maximum variability was observed in the content of Zn (109–70%) and Mn (87%). The most stable values were recorded of Cu (22–34%) and Fe (35%) contents in forest phytocenoses and Ni (31%) in urban plantations.

The patterns of accumulative abilities to metals in many species were quite similar, despite differences in their absolute content in plants of forest and urban habitats. The exception is the concentration of metal pollutants by some species that form urban landscaping.

It is found that the species of arboriflora are more characterized by a weak accumulation of HMs (up to

Table 3. Ecological and geochemical differentiation of arboriflora species composition

Heavy metal	Groups of species according to intensity of metal accumulation		
	high content (≥1.5 M)	average content ($M \pm m$)	low content (≤1.5 M)
Lead	*Corylus heterophylla*	–	*Aralia elata*
	Deutzia amurensis	–	*Micromeles alnifolia*
	Lonicera maackii	–	*Salix caprea*
Nickel	–	–	*Abies holophylla*
	–	–	*Micromeles alnifolia*
Cobalt	*Philadelphus tenuifolius*	*Sorbaria sorbifolia*	*Abies holophylla*
	–	–	*Alnus hirsuta*
	–	–	*Maackia amurensis*
	–	–	*Pinus koraiensis*
	–	–	*Salix caprea*
Cadmium	*Corylus heterophylla*	*Sambucus racemosa*	*Abies holophylla*
	Deutzia amurensis	–	*Acer pseudosieboldianum*
	Eleutherococcus sessiliflorus	–	*Alnus hirsuta*
	Euonymus sacrosancta	–	*Armeniaca mandshurica*
	Lonicera maackii	–	*Betula davurica*
	Philadelphus tenuifolius	–	*Betula platyphylla*
	–	–	*Fraxinus mandshurica*
	–	–	*Fraxinus rhynchophylla*
	–	–	*Juglans mandshurica*
	–	–	*Kalopanax septemlobus*
	–	–	*Maackia amurensis*
	–	–	*Micromeles alnifolia*
	–	–	*Padus maackii*
	–	–	*Pinus koraiensis*
	–	–	*Quercus mongolica*
	–	–	*Tilia amurensis*
	–	–	*Tilia mandshurica*
	–	–	*Tilia taguetii* × *T. amurensis*
Zinc	*Aralia elata*	*Acer pseudosieboldianum*	*Acer tegmentosum*
	Betula davurica	*Ligustrina amurensis*	*Armeniaca mandshurica*
	Betula platyphylla	–	*Corylus mandshurica*
	Populus tremula	–	*Euonymus pauciflora*
	Salix caprea	–	*Euonymus sacrosancta*
	Syringa wolfii	–	*Fraxinus mandshurica*
	–	–	*Juglans mandshurica*
	–	–	*Lonicera praeflorens*
	–	–	*Malus mandshurica*
	–	–	*Micromeles alnifolia*
	–	–	*Schisandra chinensis*
	–	–	*Spiraea ussuriensis*
	–	–	*Tilia amurensis*
	–	–	*Tilia taguetii* × *T. amurensis*

Table 3. (Contd.)

Heavy metal	Groups of species according to intensity of metal accumulation		
	high content (≥1.5 M)	average content ($M \pm m$)	low content (≤1.5 M)
Copper	*Schisandra chinensis*	*Lespedeza bicolor*	–
Manganese	*Acer mono*	–	*Armeniaca mandshurica*
	Acer pseudosieboldianum	–	*Deutzia amurensis*
	Acer tegmentosum	–	*Euonymus macroptera*
	Aralia elata	–	*Euonymus pauciflora*
	Betula davurica	–	*Fraxinus mandshurica*
	Betula platyphylla	–	*Fraxinus rhynchophylla*
	Syringa wolfii	–	*Lespedeza bicolor*
	–	–	*Ligustrina amurensis*
	–	–	*Lonicera maackii*
	–	–	*Malus mandshurica*
	–	–	*Micromeles alnifolia*
	–	–	*Phellodendron amurense*
	–	–	*Philadelphus tenuifolius*
	–	–	*Salix caprea*
	–	–	*Sambucus racemosa*
	–	–	*Ulmus japonica*
	–	–	*Ulmus pumila*
	–	–	*Viburnum sargentii*
Iron	*Corylus heterophylla*	–	*Maackia amurensis*
	–	–	*Malus mandshurica*
	–	–	*Salix caprea*

M, arithmetic mean; $M \pm m$, mean and its standard error.

1.5 times and below the average in the sample). The pattern of dispersal of most of the analyzed metals remains consistent for 38 species out of 50 occurring simultaneously in natural forest and urban environments. *Maackia amurensis*, *Micromeles alnifolia*, *Malus mandshurica*, *Abies holophylla*, etc., are typical representatives of such species. This group of species in forest phytocenoses is supplemented by *Celastrus flagellaris*, *Pinus koraiensis*, *Armeniaca mandshurica*, and *Padus maximowiczii* and, in urban plantations, by *Spiraea ussuriensis*, *Carpinus cordata*, *Amorpha fruticosa*, *Aesculus hyppocastanum*, *Fraxinus pennsylvanica*, and others. Most of the mentioned species very weakly accumulate Ni, and many of them Cd and Co as well.

The studies have also showed that about half of the arboriflora species have the ability to accumulate HMs in leaves (needles) 1.5 to 4 times higher than the background levels. The high accumulation of one to three HMs was observed in 16 species of the same name in forest and urban habitats: *Corylus heterophylla* (Pb, Cd, and Fe); *Aralia elata*, *Betula davurica*, *B. platyphylla*, and *Syringa wolfii* (Zn and Mn); *Corylus heterophylla*, *Deutzia amurensis*, and *Lonicera maackii* (Pb and Cd); *Philadelphus tenuifolius* (Co and Cd); *Acer mono*, *A. pseudosieboldianum*, *A. tegmentosum* (Mn); etc. Concentrator species of Zn, Mn, and Fe were identified that accumulate metals five times and more relative to background values. In the forest communities, they include *Salix udensis*, concentrating Zn (415 mg/kg) and Mn (1153 mg/kg), and *Populus tremula* and *Syringa wolfii*, Zn (up to 218 mg/kg); in urban plantations, they are *Populus maximowiczii*, *P. nigra*, Zn (up to 440 mg/kg), *Sorbus pochuashanensis* and *Picea* sp., Mn (up to 946 mg/kg), and *Crataegus pinnatifida*, Fe (2975 mg/kg).

The background levels of metals were recorded in a small number of the arboriflora species. Among the species of the same name in forest and urban habitats, the group with the background content includes *Sorbaria sorbifolia* and *Lespedeza bicolor* with a background Cu content and *Sambucus racemosa* with a background Cd content. In forest phytocenoses, this group is supplemented by *Rhododendron mucronulatum* (Pb, Co, and Cd) and, in urban plantations, by

Table 4. Ecological and geochemical differentiation of arboriflora families

Heavy metals	Groups of plant families according to the degree of metal accumulation		
	high content (≥1.3 M)	average content ($M \pm m$)	low content (≤1.3 M)
Lead	Caprifoliaceae	Rutaceae	Aceraceae
	Celastraceae	–	Fabaceae
	–	–	Juglandaceae
	–	–	Oleaceae
Nickel	Fagaceae	Araliaceae	–
	Hydrangeaceae	Betulaceae	–
	Salicaceae	Rosaceae	–
Cobalt	Hydrangeaceae	Araliaceae	Fabaceae
	–	Oleaceae	Pinaceae
	–	–	Tiliaceae
Cadmium	Caprifoliaceae	Rosaceae	Aceraceae
	Celastraceae	–	Betulaceae
	Hydrangeaceae	–	Fabaceae
	Salicaceae	–	Fagaceae
	–	–	Juglandaceae
	–	–	Pinaceae
	–	–	Tiliaceae
Zinc	Betulaceae	Aceraceae	Shisandraceae
	Oleaceae	Fabaceae	Tiliaceae
	Salicaceae	Hydrangeaceae	–
Copper	Juglandaceae	Aceraceae	Pinaceae
	Shisandraceae	Betulaceae	–
	–	Salicaceae	–
	–	Tiliaceae	–
Manganese	Aceraceae	Tiliaceae	Caprifoliaceae
	Araliaceae	–	Celastraceae
	Betulaceae	–	Hydrangeaceae
	Fagaceae	–	Rutaceae
	Shisandraceae	–	Ulmaceae
Iron	Hydrangeaceae	Aceraceae	Fabaceae
	–	–	Salicaceae
Ash content	Hydrangeaceae	Araliaceae	Betulaceae
	Ulmaceae	Caprifoliaceae	Fabaceae
	–	Celastraceae	Fagaceae
	–	Oleaceae	Pinaceae
	–	Rosaceae	Tiliaceae
	–	Salicaceae	–

M, arithmetic mean; $M \pm m$, mean and its standard error.

Acer ginnala (Zn, Cu, and Fe) and *Tilia amurensis* (Ni, Mn, and Fe).

The families Hydrangeaceae (Ni, Co, Cd, and Fe) and Salicaceae (Ni, Cd, and Zn) are characterized by high total accumulation of metals among the same-name plant families of forest phytocenoses and urban plantations. A low HM content is more characteristic of the families Fabaceae (Pb, Co, Cd, and Fe), Pinaceae (Co, Cd, and Cu), and Tiliaceae (Co, Cd, and Zn). Aceraceae (Cu, Zn, and Fe), Araliaceae (Ni and Co), Betulaceae (Ni and Cu), Rosaceae (Ni and Cd), and Tiliaceae (Cu and Mn) tend to families of the background HM level.

Many species with high accumulative abilities to HM can be successfully used as "living filters" in the state program for creating a comfortable urban environment. The species of the background metal content are of practical interest as phytoindicators in monitoring undisturbed forest ecosystems and assessing the condition of plant communities under ecologically unfavorable conditions.

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CONFLICT OF INTEREST

The author of this work declares that she has no conflicts of interest.

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