Urban Greening in Forest Steppe and Steppe Zones of Russia: Solving the Problems

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For citation:
Sokolskaya O. B., Vergunova A. A., Tokareva V. M. Urban Greening in Forest Steppe and Steppe Zones of Russia: Solving the Problems. *Scientific Research and Innovation. 2020;1(2):113-122*
DOI:10.34986/MAKAO.2020.2.2.006

Competing interests:
The authors declare no competing interests.

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Received: 9 June 2020
Revised: 25 June 2020
Published: 15 July 2020

Abstract: There are many settlements, including cities, in the forest steppe zone of Russia where the problem of urban greening is relevant. This study is aimed at compiling the optimal assortment of green spaces based on investigating their long-term resistance to the aggressive environment of the streets and the ability to absorb heavy metal products from the atmosphere. Our studies were conducted for 16 years on the streets of Saratov and other settlements of Saratov Oblast. Different types of planted green spaces were monitored, their growth rates and living conditions were observed. In the past eight years, computer-aided tree diagnostic devices have been used: Resistograph, Arbotom®, and Dynatim™. Using Resistograph is the most reliable way to diagnose wood. An ultrasound tomograph Arbotom® processes the data from each sensor and creates a color picture of investigated section of a tree trunk, which can be used to determine healthy wood, rotten wood and cavities. Using the Dynatim™ device, we can determine whether a tree may fall down under the influence of wind pressure. The studies took into account microclimatic features, soil properties, dust resistance, gas pollution, and vehicle exhaust emissions. Our research results are collected into tables listing major green spaces that absorb harmful emissions. Their winter hardiness, growth rate, size class, relation to light and soil conditions, moisture, gas resistance, and types of urban green spaces are indicated. The main result includes an assortment of resistant trees and shrubs that can exist in an aggressive street environment. The practical application of our results is in conducting a competent, scientifically based policy of city services in street landscaping, perimeter landscaping of garden squares, gardens and parks located close to the roadways.

Keywords: urban greening, heavy metals in the atmosphere, pollutants, dust, plant growth, resistance to aggressive environment, green spaces, Arbotom®, Resistograph, Dynatim™, streets, roadway, garden squares, parks.

Introduction

The relevance of our study is justified by an ongoing massive destruction of green spaces, caused, first, by the old age of green spaces, second, by insufficient experience of landscaping services, third, by problems in determining the condition of green spaces, and fourth, by an insufficient assortment of resistant planting material available to the municipality. After significant destruction of green spaces in Saratov, a large number of empty territories emerged, without any vegetation or shade, with dust and severe gas contamination.

Planting material offered by city services is not compensatory due to low crown biomass; it perishes due to improper selection of trees and shrubs. It is important to know and understand that, in the absence of an array of green spaces, health of the city residents is affected by prolonged exposure to small doses of various harmful substances in the city air, including exhaust gases from vehicles. For example, among the most dangerous proven causes of cancer and other diseases are aromatic hydrocarbons (benzo[a]pyrene) triggering lung, skin and bladder cancer; benzene causing leukemia (blood cancer); nitroso compounds (nitrites, nitrates) instigating gastric, esophageal, liver and brain cancers; heavy metals (nickel, mercury, lead, arsenic, cadmium, beryllium, chromium, cobalt) promoting skin, lung, prostate and gastric cancers; vinyl chloride (the compound used to make plastics), a plastic carcinogen stimulator in the lungs, liver, and blood; aflatoxin (metabolic product of mold) inducing liver cancer; Sulphur dioxide SO_2, a toxic substance that causes coughing, sore throat, and (at higher concentrations) suffocation and pulmonary edema; carbon monoxide instigating physiological disorders and – at higher concentrations – immediate death; chlorine fumes, in high concentrations prompting throat and esophageal burns, respiratory failure, increased blood pressure, anemia and atherosclerosis; sulfur dioxide instigating chronic bronchitis and conjunctivitis, and, under prolonged exposure, dysautonomia, vision loss, decrease in overall performance, Parkinson's disease, and encephalopathy.

The goal of our study was to identify resistant and sustainable planting material for green spaces in aggressive environment of city streets, and to come up with assortment of trees and shrubs capable of developing in this environment and reduce its harmful effects on human health.

Methods and Materials

We used monitoring, analytical and experimental methods aimed at studying the condition of vegetation. To determine heavy metal content in inner leaf tissues, dust accumulated on leaf surface was carefully washed off for analyses. The results led to the conclusion that primary components of pollution were carbon monoxide CO, sulfur dioxide SO_2, nitrogen oxides, hydrocarbons, and dust, in which many harmful substances were accumulating.

The authors used the method of sample preparation for instrumental analysis, which was carried out on a Minotaur-1 microwave mineralizer. Further quantitative measurements were performed on Optima-2100-DV ICP optical emission spectrometer (iron, chromium, copper, mercury, lead, cadmium) and by atomic absorption chromatography on Kapel®–104T appliance with computer processing of the results using Multichrome program.

Content of heavy metals was determined by their accumulation in a biomass of the trees growing on Saratov streets with varying intensities of vehicular traffic. Trees are very accurate and sensitive indicators of environmental conditions. Studies have shown that the dynamics of heavy metal accumulation in tree leaves accurately reflects the degree of air pollution [1–7].

The selection of the assortment for green spaces was carried out based on the results of sixteen-year monitoring. During this period, residents of downtown Saratov planted trees and shrubs offered by the researchers, and vital state of those was observed *sensu* the method by V. A. Alekseev. The vital state of trees was also studied *via* computer-aided tree diagnostic devices, such as Resistograph providing the most reliable wood diagnostics, and an ultrasound tomograph Arbotom® processing the data from each sensor and creating a color picture of investigated tree trunk section, which could be used to identify healthy wood, rotten wood and internal cavities.

Using the Dynatim™ device, we could determine whether a tree may fall down under the influence of wind pressure. Our studies took into account microclimatic features, soil properties, as well as resistance to dust, gas contamination and vehicle exhaust emissions. The most fast-growing and resistant to aggressive environment species of street trees and shrubs were selected and included into the proposed planting material assortment for widespread use on the sidewalks in Saratov.

Results

Studies have shown that many arboraceous species were able to prevent many diseases, including cancer (Table 1) [8].

TABLE 1.
Arboraceous Plants Providing Cancer Prevention

Tree and shrubs species	Substances harmful to health
Úlmus laévis *Úlmus glábra*	Carbon dioxide (CO_2) Sulphur dioxide (SO_2) Benzene (C_6H_6, PhH) Carbon monoxide (CO) Benzo[*a*]pyrene ($C_{20}H_{12}$) Heavy metals: (Pb, Cd, Cu, Zn, Ni, Co, Fe, Cr, Mn)
Pópulus álba *Pópulus nígra var. itálica, or Populus nigra f. pyramidális*	Sulphur dioxide (SO_2) Carbon monoxide (CO) Lead (Pb) Benzene (C_6H_6, PhH) Benzidine (1,1'-biphenyl-4,4'-diamine) ($C_{12}H_{12}N_2$) Benzo[a]pyrene ($C_{20}H_{12}$) Heavy metals: (Pb, Cd, Cu, Zn, Ni, Co, Fe, Cr, Mn)
Ácer negúndo	Sulphur dioxide (SO_2) Nitrogen oxides ($15NO_2$) Carbon monoxide (CO) Benzene (C_6H_6, PhH) Heavy metals: (Pb, Cd, Cu, Zn, Ni, Co, Fe, Cr, Mn)
Aésculus hippocástanum	Lead (Pb) Benzene (C_6H_6, PhH) Heavy metals: (Pb, Cd, Cu, Zn, Ni, Co, Fe, Cr, Mn)
Syrínga vulgáris	Sulphur dioxide (SO_2) Carbon monoxide (CO) Benzene (C_6H_6, PhH)
Caragana arborescens *Robinia pseudoacacia*	Sulphur dioxide (SO_2) Chlorine (Cl) and its compounds Carbon monoxide (CO)
Bérberis vulgáris *Berberis thunbergii*	Sulphur dioxide (SO_2) Carbon monoxide (CO)
Quercus robur L.	Arbon dioxide (CO_2) Nitrogen oxides ($15NO_2$) Carbon monoxide (CO) Heavy metals: (Pb, Cd, Cu, Zn, Ni, Co, Fe, Cr, Mn)
Fráxinus excélsior *Fraxinus. lanceolata Borkh.*	Sulphur dioxide (SO_2) Nitrogen oxides ($15NO_2$) Carbon monoxide (CO) Heavy metals: (Pb, Cd, Cu, Zn, Ni, Co, Fe, Cr, Mn)
Philadelphus coronarius	Sulphur dioxide (SO_2) Carbon monoxide (CO)
Elaeágnus angustifólia	Chlorine (Cl) and its compounds Carbon monoxide (CO) Benzene (C_6H_6, PhH)
Cornus alba	Sulphur dioxide (SO_2) Nitrogen oxides ($15NO_2$)

The authors studied the dynamics of heavy metal and carbon monoxide accumulation in the atmosphere of Saratov on the streets with different traffic intensities. Samples were taken at locations with predetermined traffic intensity, which was calculated based on the number of lanes and 24-hr traffic intensity monitoring. A preliminary comparative analysis resulted in identification of three locations for sampling the plant material: location 1 with a two-lane low-intensity traffic; location 2

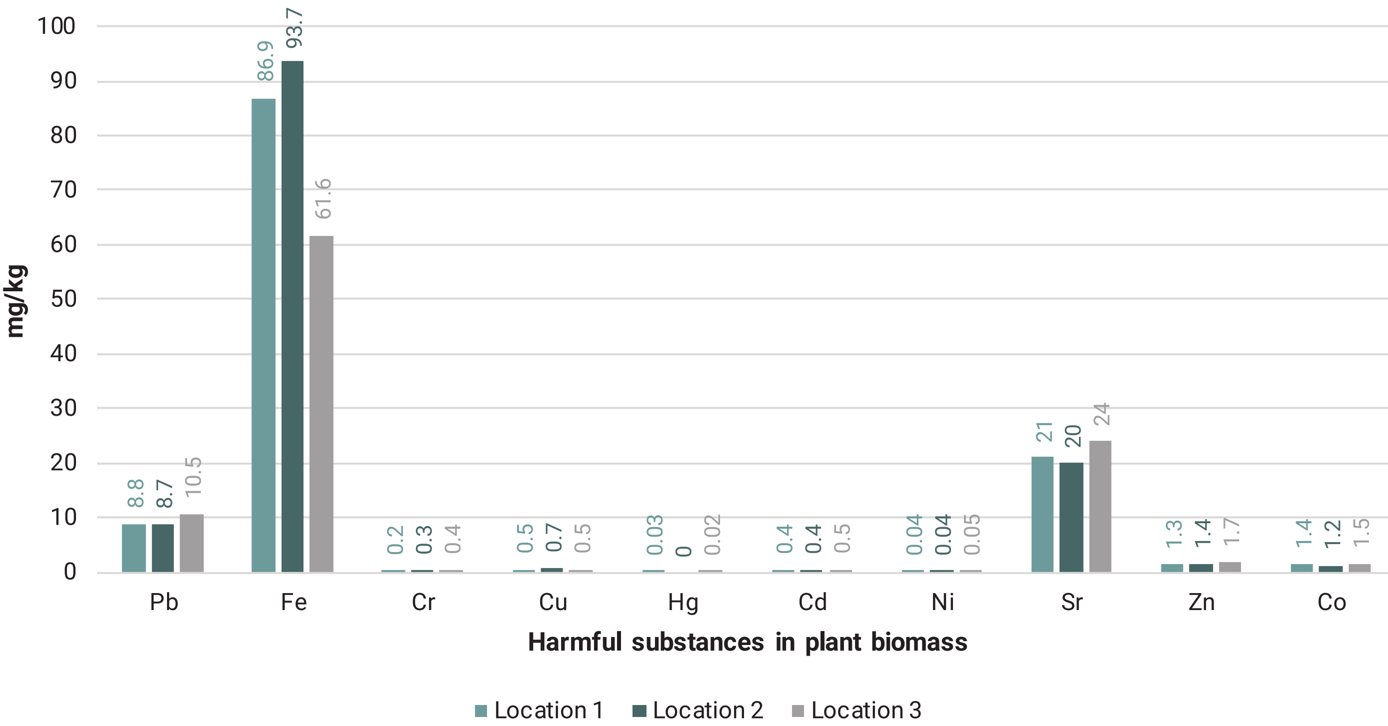


Figure 1. **Means of harmful substances (mg/kg) at sampling locations, where location 1 is a street with two-lane low-intensity traffic; location 2 – two-lane medium-intensity traffic; location 3 – four-lane heavy traffic**

with a two-lane medium-intensity traffic; location 3 with a four-lane heavy traffic. Average sample method was used for selection of leaves.

At least 400–500 g of mixed leaf sample was taken from each tree. The metal content in the leaves was studied on 65 trees on different week days. The research results showed the presence of heavy metals (cadmium, lead, zinc, copper, nickel, cobalt, chromium, mercury, iron), absorbed by plant tissues, in leaf ash. The results were processed by the methods of mathematical statistics. Medians of concentration values at sampling locations and means were calculated (Figure 1).

Thus, differences in the ratios of harmful substances in plant biomass were due to different concentrations of hazardous substances in the air at different sampling locations. Our data indicated significantly higher Pb, Fe, Cd and Cu content at all sampling locations (compared with control values), while for Cr and Zn this was true at two locations out of three. It is worth noting that Pb, Fe and Zn content increased with traffic intensity. For other heavy metals, the differences were not unidirectional. The lowest heavy metal content was observed in the street with a low-intensity traffic (location 1), however, even in this case, Fe, Pb and Cd content significantly exceeded the control values. All indicators increased in the street with heavy traffic (location 3). Heavy metal accumulation in plant biomass was investigated in dynamics at the end of the growing season. We conducted a comparative study of absorptive capacity of plant biomass in various tree species in relation to harmful substances (Figure 2).

The largest amounts of lead accumulated in the leaves of *Acer negundo* L., *Ulmus laevis* Pall., and *Pópulus nígra var. itálica*. However, in all studied tree species, lead exceeded MPC value by 1.5–2 times. Significant amounts of zinc and copper accumulated in the leaves of *Ulmus pumila* L. and *Ulmus laevis* Pall., correspondingly. Cadmium accumulated well outside its normal range in *Pópulus nígra var. itálica*: 0.8 mg/kg of dry matter (twice as much as MPC value). However, CO was within the MPC limits.

Discussion

Thus, the best performance in terms of heavy metal accumulation in our study was specific for several zoned species, such as *Acer negundo* L., *Ulmus laevis*

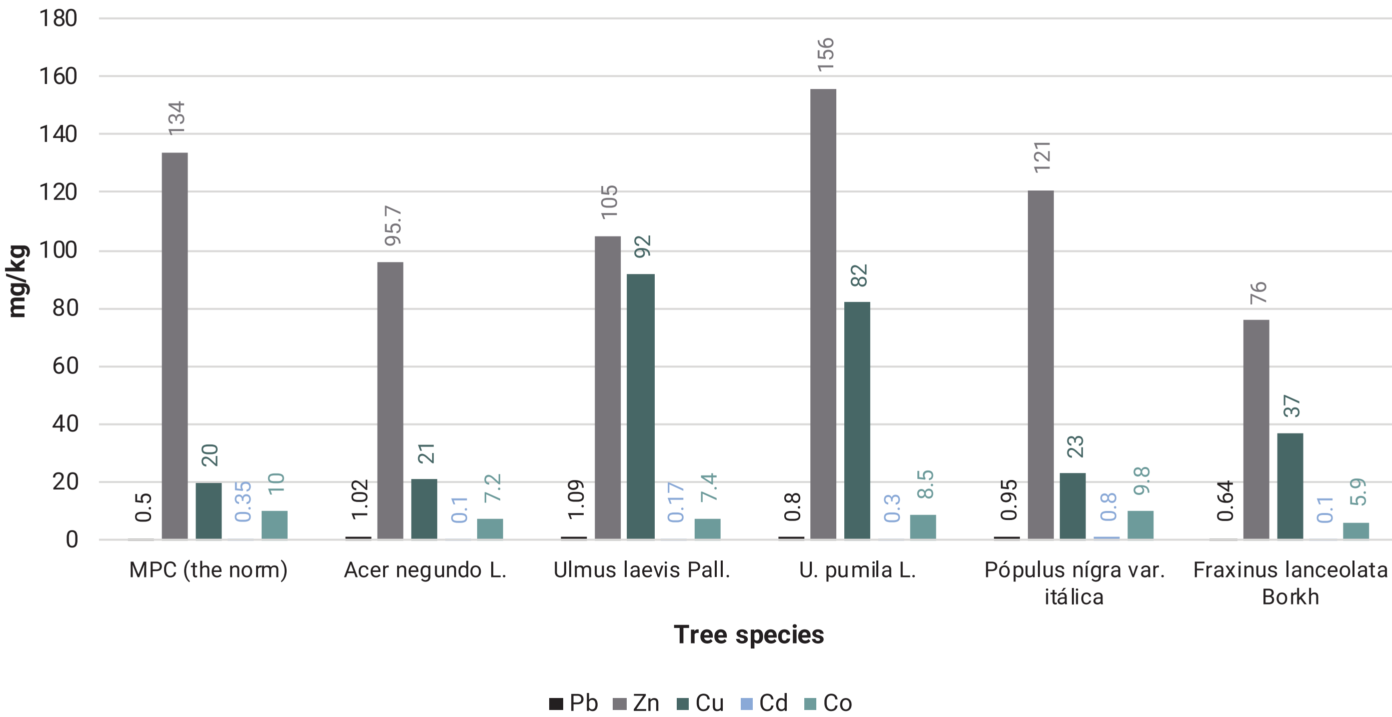


Figure 2. **Means of the content of harmful toxic substances in the tree biomass (mg/kg of dry matter)**

Pall., and *Pópulus nígra var. itálica*. All of those tree species are currently intensively cut down in favor of ornamental trees and shrubs, which allows us concluding that the replacement made on the streets of Saratov is absolutely ineffective.

After conducting a monitoring of trees and shrubs planted 16 years ago, we proposed an assortment of trees and shrubs resistant to harsh environmental conditions in the streets of Saratov (Table 2) [9].

Conclusions

Thus, the environmental and dendrological monitoring at downtown streets of Saratov confirmed the trend of transformation of "a habitat into survival environment" and allowed us drawing the following conclusions:

1. Because of increasing traffic in the city, in order to maintain clean air and good health of city residents, it is necessary to have stricter requirements for fuel quality, install filters, regulate the traffic pattern, and most importantly, use "nature's own forces", that is, green spaces, to protect the environment.

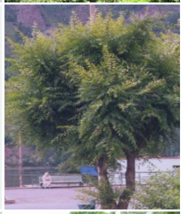
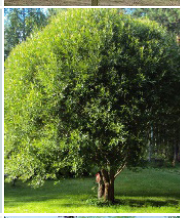
2. To recommend the city government to search for new effective and investment-wise attractive solutions for scientifically-based landscaping, create intercepting parking lots at the entrances to the regional center, and work out public transportation routes for transporting the residents to the downtown area, along with developing electric public transport.

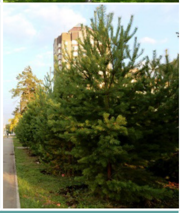
3. It was established that the dynamics of heavy metal accumulation in Saratov air is well correlated with the intensity of road traffic and has a steady tendency to increase the content of these toxic substances.

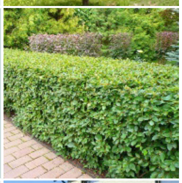
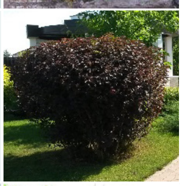
4. It was revealed that zoned tree species, such as *Acer negundo* L., *Ulmus laevis* Pall., *Pópulus nígra var. itálica*, and *Fraxinus lanceolata* Borkh., trap and accumulate harmful substances deposited on them with dust, thereby purifying city air and protecting urban residents from the ailments caused by toxic metals.

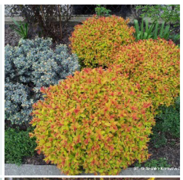
5. On the streets with heavy traffic, to recommend planting the species, which can perform protective function of garden squares, gardens, and parks, when placed along the perimeter of these objects of landscape architecture: *Acer negundo* L., *Ulmus laevis* Pall., *U. pumila* L., *Pópulus nígra var. itálica*, *Fraxinus. lanceolata* Borkh. [10].

TABLE 2.
Assortment of Tree and Shrub Species for City Streets and Urban Green Spaces

1. Deciduous and coniferous trees										
1	*Úlmus laévis*	2	M, I	Av	S, SL	HM	R	U, P, G, B, GS, R	A, G, S	
2	*Ulmus pumila*	3	F, III	Ph	S, SL, LL	MX	R	P, G, B, GS, R	G, S	
3	*Úlmus glábra*	2	M, II	Av	S, SL, LL	HM	R	U, P, G, B, GS, R	A, G, S	
4	*Sálix álba*	1	F, I	Ph	SL, LL, ML	HM	R	P, G, GS, S, R	S, G,	
5	*Sálix fragílis*	1	F, III	Ph	ML, HL	MH	R	P, G, B, GS, R, S, L	A, S, G, R	
6	*Salix schwerinii, (S. schwerinii x S. udnesis)*	2	F, III	Ph	LL, ML, HL	H	R	P, G, GS	G, S	
7	*Cotinus coggýgria*	1	F, III	Av	ND	H	R	P, G, GS	G, S	
8	*Rhus typhina*	1	F, III	Av	ND	H	R	P, G, GS	G, S	

9	*Pópulus álba*	2	M, I	Ph	SL, LL	HM	RR	P	G	
10	*Pópulus nígra var. itálica*	2	M, I	Ph	SL, LL	MH	R	P, G, B, GS, S, R	A, G, R	
11	*Fraxinus lanceolata*	2	F, II	Ph	ND	MH	R	U, P, G, GS, B, R	A, G, S, R	
12	*Pínus sylvéstris*	1	M, I	Ph	S, SL, ML, HL	XH	NR	U, P, G	Ar, A, G	
2. Coniferous shrubs										
13	*Juníperus sabína*	3	S, III	Ph	S, R	MX	RR	G, GS, L, R	G, S, H	
14	*Juniperus horizontalis*	3	S, III	Ph	S, R	M	RR	GS, L, R	G, S, H	
15	*Juniperus scopulorum*	3	S, III	Ph	S, R	MX\dt	RR	GS, L	G, S, H	
16	*Juníperus commúnis*	1	S, I–III	Av	S, SL, ML	XM	RR	U, P, GS, L, R	U, G, H	
17	*Pínus sylvéstris*	1	M, I	Ph	S, SL, ML, HL	XH	NR	U, P, G	Ar, A, G	

3. Deciduous shrubs											
18	*Berberis thunbergii*	3–5	M, III	Ph	LL, ML	M\dt	BR	G, B, GS, R	G, H, S, B	
19	*Hydrangéa arboréscens*	4	F, II	Av	LL, ML	M	RR	GS, G, L	G	
20	*Córnus álba*	2	F, I	Av	SL	MH	RR	P, G, GS, B, L, R	S, G, H	
21	*Salix purpurea*	2	F, I	Ph	S, SL	HM	R	P, GC, GS, B, R	S, G, H, B	
22	*Caragána arboréscens*	1	F, I	Av	S, SL, LL	MX	RR	U, P, G, L, R	E, R, G	
23	*Cotoneáster lucídus*	2	M, II	Av	ND	MX	R	GS, B, G, L, R	H, G	
24	*Potentilla fruticosa*	2	M, II-III	Av	ND	XM	BR	GS, L, R	H, B, G	
25	*Elaeagnus commutata*	2	M, III	Ph	ND	XM	R	P, G, GS, R	G, S	
26	*Physocarpus opulifolius*	1	F, I	Av	ND	MX	RR	P, G, B, GS, L, R	G, H, S	
27	*Syrínga vulgáris*	2	M, I	Ph	SL, LL, ML, HL	MX	BR	G, GS	S, G	

28	*Spiraea japonica*	3	F, II-III	Ph	ND	M	RR	P, G, B, GS, R, L	H, G, R	
29	*Forsythia ovata Nakai.*	2	F, II	Ph	ND	M	R	P, G, R	G, S	
30	*Philadelphus coronarius*	3	F, I	Av	SL, LL, ML	MH	R	P, G, B, GS, R	S, G, B	
31	*Rosa sp.*	3	F, I	Av	SL, LL, ML	MH	R	P, G, B, GS, R	S, G, B	

* Winter hardiness: 1 – do not freeze, 2 – only the ends of annual shoots at young age freeze in cold winters, 3 – significant freezing of annual shoots at young age, 4 – severe freezing, planting is feasible solely in protected places, 5 – plant parts above ground are killed by cold annually.
* Growth rate: F – fast, M – medium, S – slow.
* Size class: Trees: I (20 m and above), II (10–20 m), III (5–10 m). Shrubs: I – tall (2–5 m), II – medium (1–2 m), III – low (0.5–1 m).
* Light tolerance: Ph – photophilous, Av – with average light requirement, Sh – shade tolerant.
* Soil conditions: S – sand, SL – sandy loam, LL – light loam, ML – medium loam, HL – heavy loam, R – rocky, ND – not demanding.
* Moisture tolerance: H – hygrophyte, HM – hygromesophyte, MH – mesohygrophyte, M – mesophyte, MX – mesoxerophyte, X – xerophyte, XH – xerohygrophyte (versatile); \ cs – endure groundwater close to the surface; dt – drought tolerant.
* Gas resistance: R – resistant, RR – relatively resistant, BR – barely resistant, NR – not resistant.
* Landscaping objects: U – urban forest, P – park, G – garden, GS – garden square, B – boulevard, S – linear street planting, L – roadside lawns, R – small communal green spaces in residential neighborhoods.
* Types of landscape gardening: A – alleys in parks and gardens, G – groups and clusters, S – single plantings, Ar – arrays, H – hedges, R – rows along streets and alleys in garden squares and on boulevards, E – edges of the arrays, U – undergrowth, B – borders, V – vertical gardening.
* Most unpretentious, resistant plants requiring minimal maintenance are highlighted in color.

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