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Biogeochemical activity of park plants as an indicator of stability of wood plants

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Abstract

The relevance of the research is related to the improvement of the sustainability of park stands of the Rostov region, which have historical significance and conservation status. The long-term monitoring of the accumulation of heavy metals contributes to the establishment of the biogeochemical role of woody plants.

The purpose of the research is to identify the biogeochemical activity of parkland stands of the steppe zone based on the study of the species and age composition of woody plants and the biological absorption coefficients of heavy metals.

The coefficient of biological absorption (CBP) reflects the degree of concentration of the element in plants compared with adjacent media. KBP - the ratio of the content of the element in the dry matter to the content in the soil on which they grow. This coefficient characterizes the intensity of extraction of chemical elements from the soil. In this case, the PCU for each element is largely determined by both chemical properties and the need of plants.

The objects of research are parklands of Rostov-on-Don, Taganrog, Novocherkassk, Azov and Bataysk. They are represented by trees aged 40-50 years (75-80%). Trees over the age of 50 years (25%) are found in the city of Taganrog. On the territory of the parks of Bataysk, a fairly large percentage of plantations (37) are represented by trees up to 20 years.

It has been established that the species composition of park stands is represented by 11 species (*Quercus robur* L., *Aesculus hippocastanum* L., *Ulmus laevis* Pall, *Fraxinus excelsior* L., *Fraxinus lanceolata* Borkh, *Robinia pseudoacacia* L., *Tilia platyphyllos* Scop, *Acer platanoides* L., *Acer negundo* L., *Populus alba* L., *Populus sowietica pyramidalis* Jabl.) from 8 families (*Fagaceae, Hippocastanaceae, Ulmaceae, Oleaceae, Fabaceae, Tiliaceae, Aceraceae, Salicaceae*). Revealed dominant species in the park landscapes of the studied cities.

Based on the monitoring of the park landscapes of the city of Rostov-on-Don, it was revealed that during the growing season, the largest amount of metals deposited on the leaf surfaces of maple and linden. The selectivity of metal deposition by individual species is manifested in the accumulation of certain metals by them.

On all studied objects (2002-2018), total accumulation of heavy metals by leaves of woody plants was calculated. The maximum coefficients of biological absorption were established: according to Zn(*Populus sowietica pyramidalis*, *Populus alba, Ulmus laevis*); Cu (*Fraxinus excelsior, Aesculus hippocastanum, Quercus robur); Ni (Acer platanoides, Populus alba, Ulmus laevis*). The minimum coefficient of biological absorption is set for Zn and Cu for *Acer negundo*, for Ni - *Tilia platyphyllos*.

A register of woody plants has been compiled to reduce the biogeochemical activity coefficient: *Fraxinus excelsior* = *Populus sowietica pyramidalis* = *Populus alba* (0,4) > *Aesculus hippocastanum* = *Quercus robur*

(0,3) > *Acer platanoides* = *Tilia platyphyllos* = *Ulmus laevis* = *Robinia pseudoacaciaia* (0,2) > *Acer negundo* = *Fraxinus lanceolata* (0,1).

Thus, the content of macroelements in plants has been established, which is determined by the systematic position - family, genus and species. The parameters of the coefficients of biological absorption, and their dynamics depending on time (for example, the vegetation phase), the age of the organism, the soil, are recommended to be used as indicators of sustainability and selection of the assortment when renovating historical park landscapes.

Keywords

park stands of the Rostov region, steppe zone, woody species, species composition, heavy metals (Zn, Cu, Ni, Pb, Cd), biogeochemical activity, coefficient of biological absorption, indicators, stability

Introduction

Woody plants are sensitive indicators of the state of the ecological environment (Dubinin, 2007; Park landscapes, 2019). Heavy metals accumulate in them not only from soil, but also from air (Giniyatullin, 1995; Neverova, 2003; Prokhorova, 1998). The main intake of heavy metals in plants is carried out by absorption of roots. This process can be passive (non-metabolic) and active (metabolic), and the rate of absorption of heavy metals by roots positively correlates with their available stock in the soil (mobile forms) in contact with the root system. Passive absorption of heavy metals occurs by diffusion of ions from the soil solution into the root endoderm. The following are distinguished: simple diffusion through the pores of the membrane along the concentration gradient, passage through the pores of the membrane with a solvent flow, flow in the process of lipid diffusion involving carriers and exchange diffusion (Dubinin, 2007; Chernyshenko, 2018; Barnes, 1999).

The presence of a variety of ways of receipt of heavy metals in plants suggests the existence of two leading factors in the formation of elemental chemical composition of plants: genetic and environmental. Everyone's share varies depending on changes in environmental conditions (Semenyutina, 2016; Semenyutina, 2018). In accordance with the geochemical situation of phytocenoses trophic requirements of plants, their elemental composition mainly reflects the work of genetic control (Ilyin, 1991). Under such conditions, the selective and characteristic absorption of metal ions by plant tissues is maintained. The environmental factor prevents this in cases when the habitat is enriched with mobile forms of heavy metals (Podkolzin, 2016; Sidorovich, 2007; Semenyutina, 2019).

According to A. L. Kovalevsky's classification (Kovalsky, 1974), plants can be divided into weak concentrators (Cobe does not exceed 4) and moderate concentrators (Cobe within 4...25). Weak cadmium concentrators are all species except birch and poplar; lead is birch, maple is ashy, Rowan, elm is smooth. Moderate lead concentrators – Holly maple, poplar, Linden, ash.

The accumulation of zinc in most species is in the range from 0.5 to 40 mg/kg the Maximum content of Zn (36,5 mg/kg) in the leaves set for a poplar (*Populus sowietica pyramidalis, Populus alba*) growing near the motorway. Maximum permissible concentrations of Zn are recommended in the range from 15.0 to 300.0 mg/kg dry matter (Ilyin, 1994). Phytotoxic consider the concentration of Zn more than 400.0 mg/kg. Data on the normal content of Ni in various plants are quite contradictory: from 0.1-1.0 (Ilyin, 1991) to 8.1 mg/kg at a critical concentration of 3.0 mg/kg.

According to N. V. Prokhorova [Prokhorova, 1998], in the forest-steppe and steppe Volga region representatives of the genus *Populus* and all this. *Salicaceae* in General are the main concentrators of Zn compared to other species.

The comparison of the vibration limits does not provide uniform critical levels for woody vegetation, therefore it is necessary to study the species specialization of plants in the absorption of different doses of metals in different landscape-geochemical conditions (Ilyin, 1991; Park landscapes, 2019).

The aim of the research is to identify the biogeochemical activity of Park plantations of the steppe zone on the basis of the study of species, age composition of woody plants and biological absorption coefficients of heavy metals.

Material and methods

Objects of research – parkland Rostov-on-don, Taganrog, Novocherkassk, Azov and Bataysk. For the study area is characterized by a temperate continental climate. Winter is usually cloudy and windy. Summers are windy, dry and hot. Continental features in the climate of the Rostov region are increasing in the direction from the North-West to the South-East (figure 1).

During the research period (2002-2018) the content of heavy metals (cadmium, lead, zinc, copper, Nickel) was determined):

1. in flushes from leaves, i.e. the amount of pollutants deposited on the surface of the leaf plate was determined;
2. in the ash of the leaves, i.e. the amount of toxicants absorbed by the tissues.

To characterize the geological role of biogenic migration of heavy metals B. B. Polynov proposed to use the biological absorption coefficient.

The biological uptake coefficient reflects the degree of element concentration in plants compared to adjacent media.

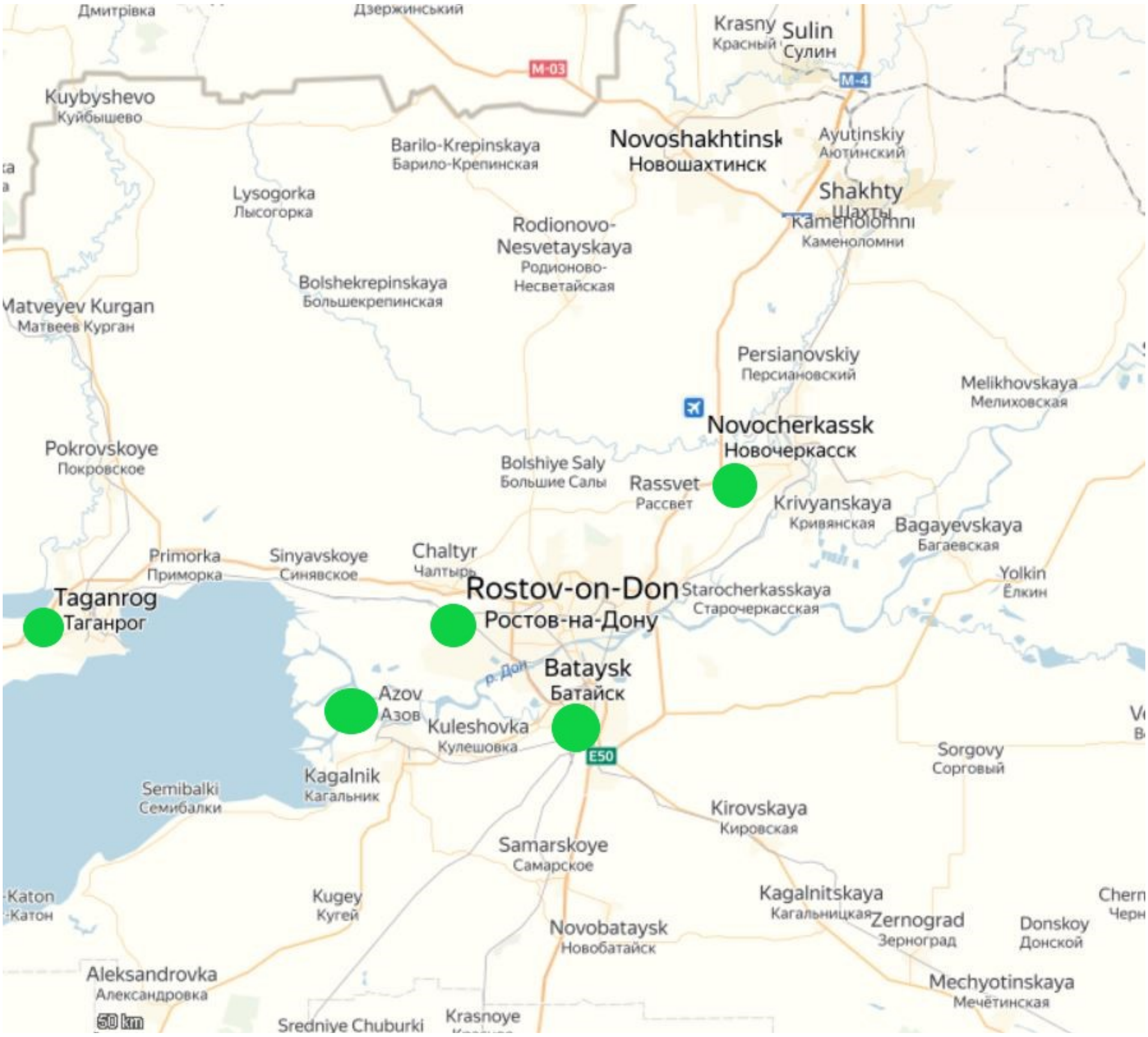

Figure 1. Map of Rostov region – the location of the objects (Landscape, 2014)

The biological uptake coefficient is the ratio of the element content in the dry matter to the content in the soil on which they grow. This coefficient characterizes the intensity of extraction of chemical elements from the soil. In this case, the biological uptake coefficient for each element is largely determined by both the chemical properties and the need of plants.

Results and discussion

Woody plants of Park landscapes of the Rostov region are mainly *represented* by 11 species from 8 families (*Fagaceae, Hippocastanaceae, Ulmaceae, Oleaceae, Fabaceae, Tiliaceae, Aceraceae, Salicaceae*). These plants are typical of Park greenery of the steppe zone: *Quercus robur* L., *Aesculus hippocastanum* L., *Ulmus laevis* Pall., *Fraxinus excelsior* L., *Fraxinus lanceolata* Borkh., *Robinia pseudoacacia* L., *Tilia platyphyllos* Scop., *Acer platanoides* L., *Acer negundo* L., *Populus alba* L., *Populus pyramidalis sowietica* Manufacture. Many of these plants have a long history of introduction in the steppe zone (Kvartovkina, 2007; Growth, 2018; Semenyutina, 2018; *Kruzhilin*, 2018).

When studying species diversity in the Park landscape of the Rostov region it is noted that the landscaping of the city of Azov (figure 2) greater preference for maple and ash (33%), locust gleditsia pseudoacacia and three-thorns.

From coniferous: pine Crimean and ordinary (8%). A single hornbeam, poplar, linden.

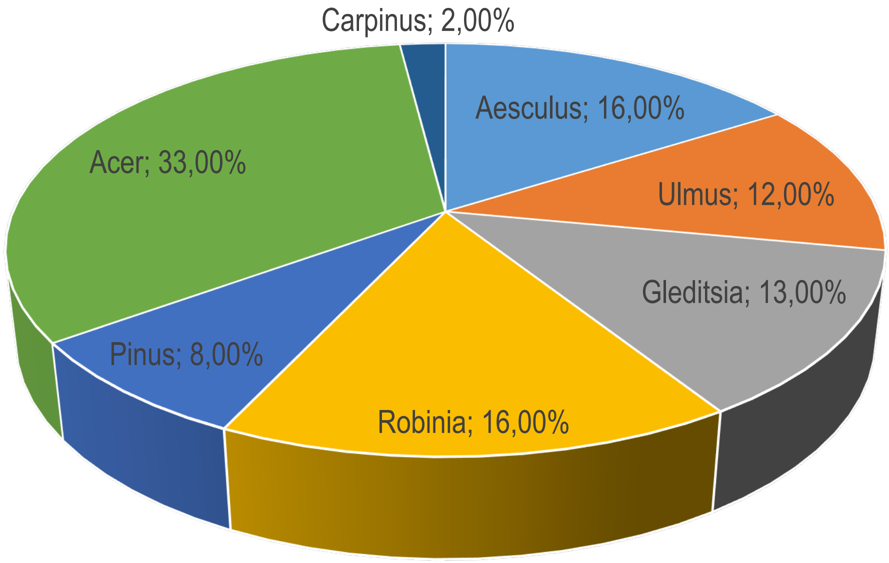

Figure 2. Species diversity in the Park landscapes of Azov

Park landscapes of the city of Novocherkassk (figure 3) are represented by Robin pseudo-acacia (31 %), maple ash and Holly, Crimean pine and chestnut horse ordinary (17 %).

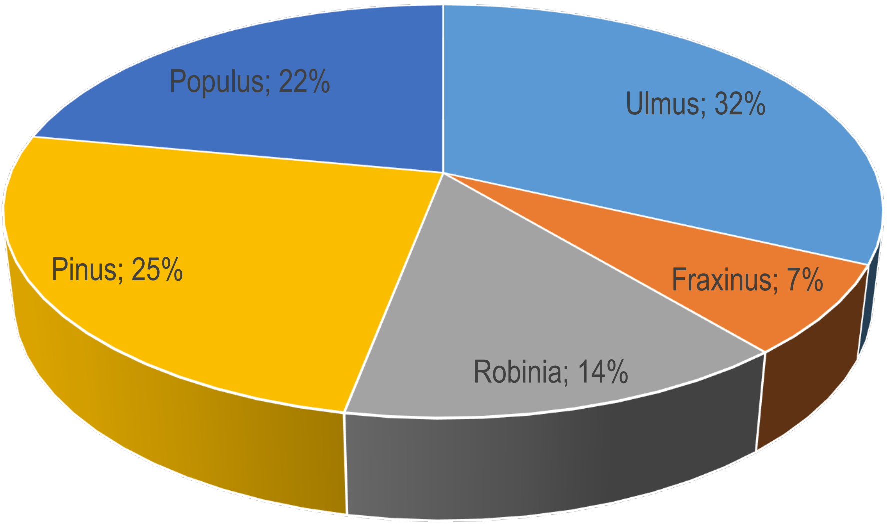

Figure 3. Species diversity of woody vegetation in Park landscapes of Novocherkassk

Elm (32%) and hybrid forms of poplars (22%) are dominant species in the Park landscapes of Bataysk (figure 4).

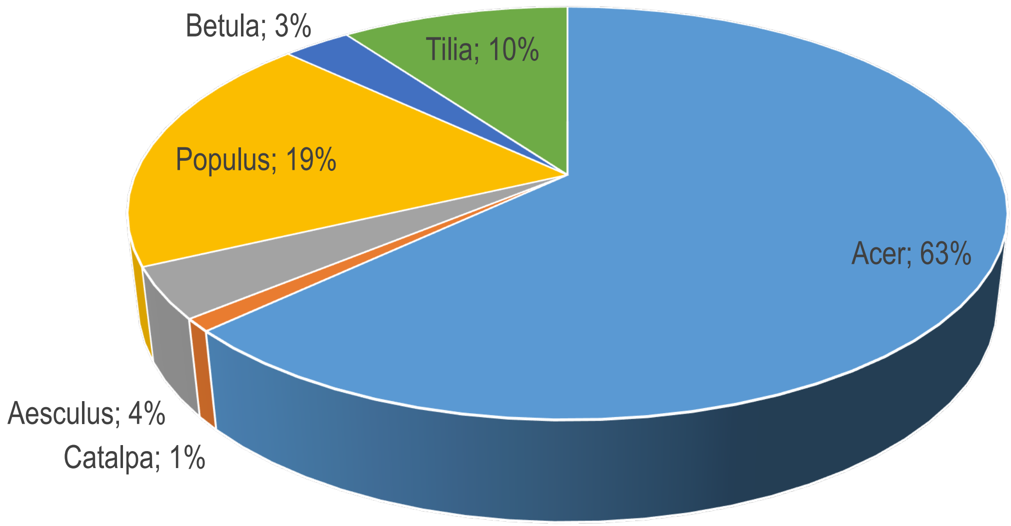

Figure 4. Species diversity of woody vegetation in Park landscapes

Coniferous plants are represented by Crimean pine (25 %), arborvitae, biota and junipers are rare. Robinia pseudoacacia presented in ordinary and solitary plantings. Maple Holly – the predominant species in the parks of the city of Rostov-on-don. Ordinary planting on the perimeter of the parks made their poplar Soviet pyramidal (19 %), group planting of Linden, birch, chestnut and Catalpa complement the landscape diversity of parks.

When you create Park landscapes of the city of Taganrog (figure 5) the advantage given to fast growing species of locust pseudoacacia (38 %) and ash (23 %). Alley planting is mainly made of maple and linden.

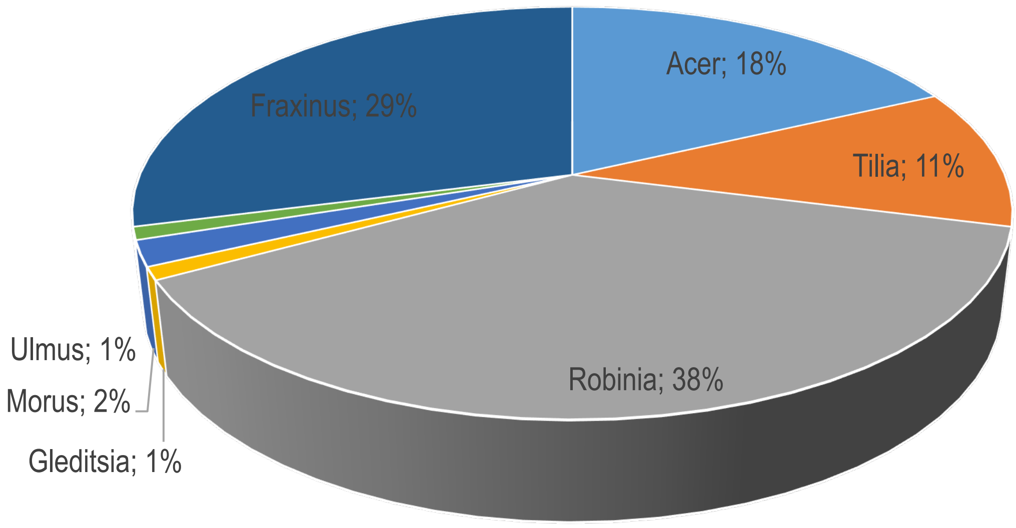

Figure 5. Species diversity of tree species in Park landscapes of Taganrog

When creating Park landscapes in the steppe zone, the main preference was given to maple Holly, ash, Robinia pseudoacacia, ash, Linden and chestnut horse ordinary (figure 6). The same trend in the range is maintained in the development of landscaping plans (Gudzenko, 2016; Pokhilko, 2009).

When examining the parks of Rostov-on-don, Gudzenko E. O. (Gudzenko, 2016) indicates that only 5 species of trees (*Acer platanoides, Fraxinus excelsior, Robinia pseudoacacia, Tilia cordata, Ulmus pumila*) and 3 species of shrubs (*Ligustrum vulgare, Syringa vulgaris, Swida alba*) are steadily used in landscaping of Park landscapes of the steppe zone, which reduces their biological stability.

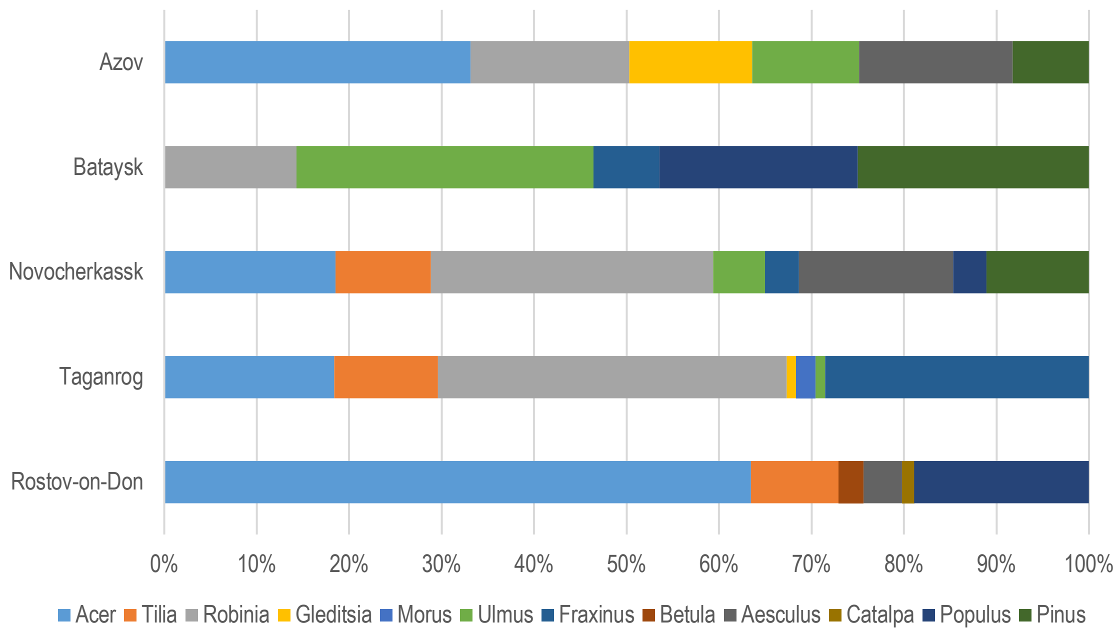

Figure 6. Representation of tree species by cities

Park plantations of Taganrog, Novocherkassk, Azov and Bataisk (figure 7) are mainly represented by trees aged 40-50 years, i.e. at the age when a number of works are necessary to maintain biological stability and decorative effect.

Trees over the age of 50 years are found in the city of Taganrog. This is due to the fact that most Park landscapes have historical significance and conservation status, which limits the possibility of sanitary logging.

On the territory of the parks of the city of Bataysk city quite a large percentage of plantations (37 %) represented by trees under the age of 20 years, indicating that planting in recent years.

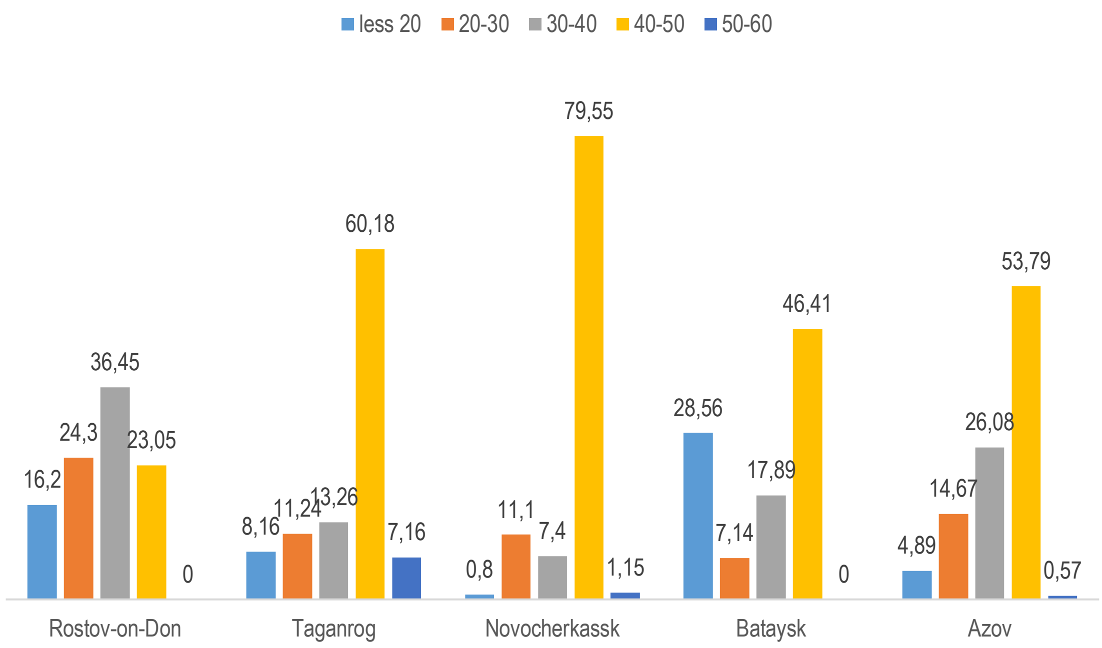

Figure 7. Age structure of parkland

The content of heavy metals on the sheet surface is ambiguous. When evaporation, transpiration and rain fall, the concentration of trace elements in plants can vary more than 10 times. The differences in the efficiency of leaching of different elements are comparable with their functions and metabolic bonds. For example, the easy removal of Pb and Cd during flushing is due to the fact that these elements are mainly present as sediment on the leaf surface, without significant penetration of these metals into the leaf tissue.

During the growing season in Park landscapes of Rostov-on-don the greatest number of metals was deposited on the leaf surfaces of maple and Linden (figure 8).

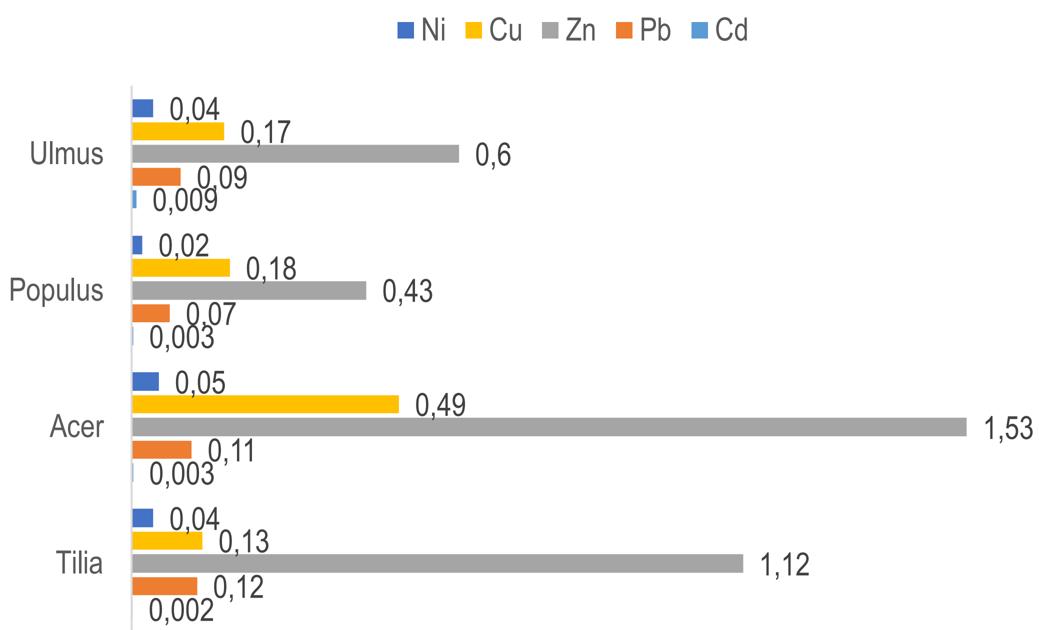

Figure 8. Content of heavy metals on the surface of the leaf plate of Park plantations in Rostov-on-don

On the territory of Park landscapes of Novocherkassk: maple and poplar (figure 9).

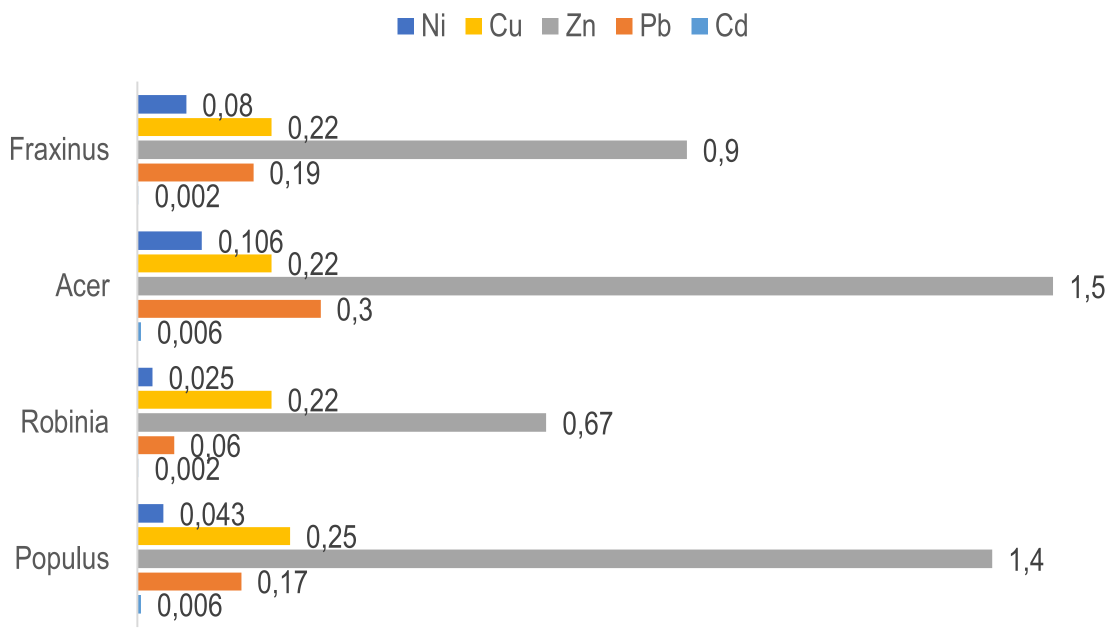

Figure 9. Content of heavy metals on the surface of the leaf plate of Park plantations of Novocherkassk

The parks of the city of Taganrog: Robinia pseudoacacia, maple and ash (figure 10).
Selectivity of metal deposition by individual species is manifested in the accumulation of certain metals.

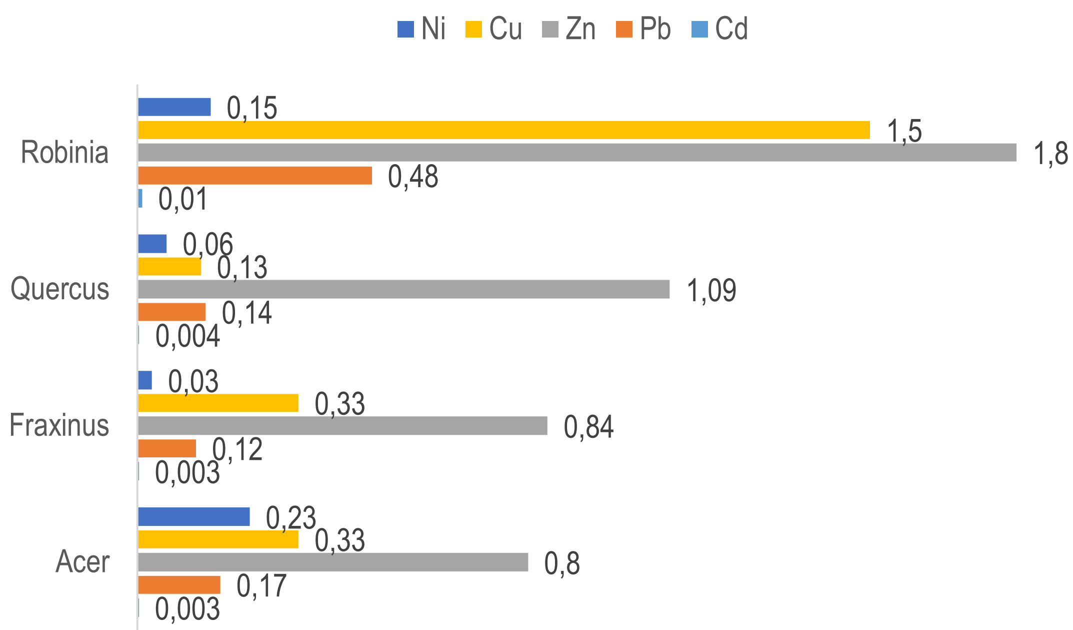

Figure 10. Content of heavy metals on the surface of the leaf plate of Park plantations of Taganrog

Cadmium uptake by leaves was not established during the entire study period.

According to our data, the content of lead in the leaves of tree species was observed only in trees growing near highways, but it does not reach even the lower limit of MPC (from 0.5-1.2 to 10.0-20.0 mg/kg of dry matter). In our studies, there are no exceedances of MPC in the content of Zn in the leaves of tree species.

The ability of leaves to accumulate Zn can be determined by the following order of tree species: *Populus sowietica pyramidalis* > *Populus alba* > *Fraxinus excelsior* > *Quercus robur* > *Acer platanoides* > *Ulmus laevis* > *Robinia pseudoacacia* > *Aesculus hippocastanum*.

Maximum cu accumulation was observed for *Quercus robur* (14.3 mg/kg) and *Aesculus hippocastanum* (13.5 mg/kg) species. The minimum cu content was recorded in *Acer negundo* leaves (5.3 mg/kg).

The ability of leaves to accumulate Cu can be determined by the following order of tree species: *Quercus robur* > *Aesculus hippocastanum* > *Robinia pseudoacacia* > *Tilia platyphyllos* > *Populus alba* > *Acer platanoides* > *Ulmus laevis* > *Fraxinus excelsior*.

The content of Ni in the leaves of tree species of Park landscapes does not exceed MPC (20.0-30.0 mg/kg). The maximum concentration of this element (from 1.05 to 0.65 mg/kg) was detected in the following species: *Acer platanoides*, *Fraxinus excelsior*, *Robinia pseudoacacia* (in descending order). The minimum Ni concentration is typical for Quercus robur leaves (0.15-0.3 mg/kg).

The ability of leaves to accumulate Ni can be determined by the following order of tree species: *Acer platanoides* > *Fraxinus excelsior* > *Robinia pseudoacacia* > *Populus alba* > *Populus*sowietica pyramidalis* > *Ulmus laevis* > *Acer negundo*.

The maximum accumulation of all the studied heavy metals in leaves is typical for *Populus*sowietica pyramidalis, Populus alba*. On the basis of the received long-term data of research the total index of accumulation of heavy metals by leaves of tree breeds of Park landscapes on the cities was calculated.

More clearly, the results can be presented in the form of a sequence of species arranged in descending order of the total indicators of accumulation of heavy metals: *Populus sowietica pyramidalis > Populus alba > Quercus robur > Fraxinus excelsior > Aesculus hippocastanum > Robinia pseudoacacia > Acer platanoides > Tilia platyphyllos > Ulmus laevis.*

The ability to absorb the studied metals by woody plants of Park landscapes is reflected in figure 11.

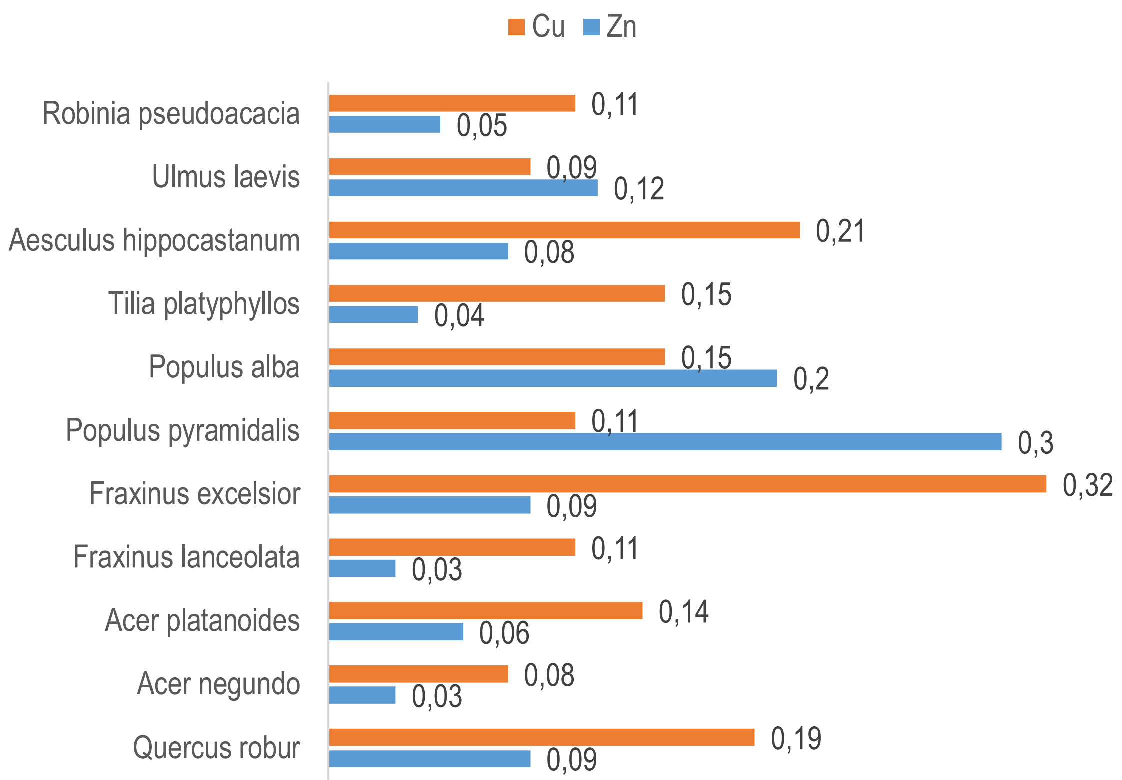

Figure 11. Biological absorption coefficients of zinc and copper by the studied tree species

The maximum biological absorption coefficients were determined by: Zn for species: *Populus*sowietica pyramidalis, Populus alba, Ulmus laevis*; Cu for species: *Fraxinus excelsior, Aesculus hippocastanum, Quercus robur*; Ni for species: *Acer platanoides, Populus alba, Ulmus laevis*.

The minimum biological absorption coefficient is set by Zn and Cu for *Acer negundo*, Ni - *Tilia platyphyllos*.

Biological lead absorption coefficients are only established for *Quercus robur* (0.01) and *Acer negundo* (0.01).

The coefficient of biogeochemical activity (BHA) allows us to judge the overall ability of plants to concentrate chemical elements due to their extraction from the soil. The method of its calculation includes summation of all biological absorption coefficients regardless of their numerical value. It is by such concentrations that one can judge the absorptive capacity of woody plants, the resistance of plants to metal pollution and changes in the level of soil pollution.

The coefficients of biogeochemical activity of the studied woody plants are shown in figure 12.

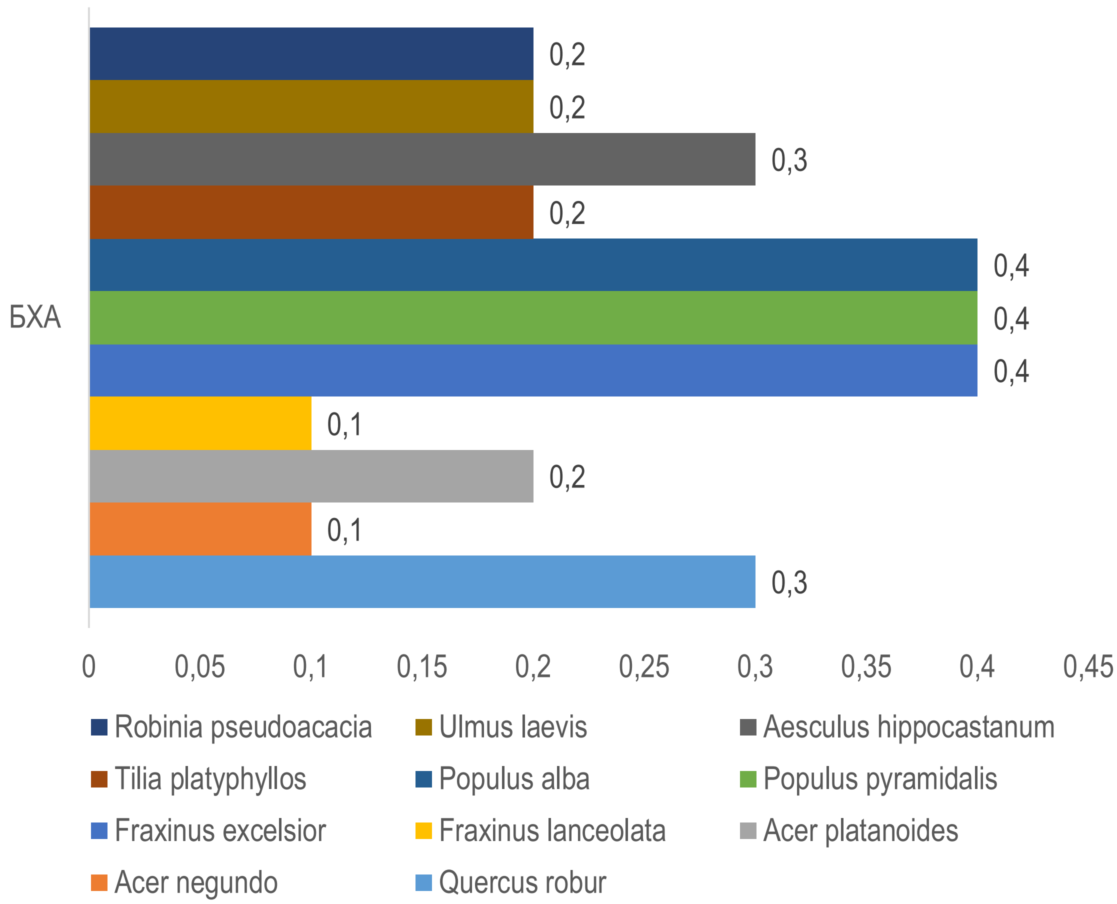

Figure 12. Coefficients of biogeochemical activity of the studied tree species

According to the coefficient of biogeochemical activity, tree species form the following series: *Fraxinus excelsior* = *Populus*sowietica pyramidalis* = *Populus alba* (0,4) > *Aesculus hippocastanum* = *Quercus robur* (0,3) > *Acer platanoides* = *Tilia platyphyllos* = *Ulmus laevis* = *Robinia pseudoacia* (0,2) > *Acer negundo* = *Fraxinus lanceolata* (0,1).

Conclusion

The prevailing types in Park landscapes of a steppe zone are: Aesculus hippocastanum L., Fraxinus excelsior L., Fraxinus lanceolata Borkh, Robinia pseudoacacia L., Quercus robur L., Ulmus laevis Pall, Tilia platyphyllos Scop, Acer platanoides L., Acer negundo L., Populus alba L., Populus * sowietica pyramidalis Jabl and three species of bushes: Ligustrum vulgare, Syringa vulgaris, Swida alba.

Single-crop landings in park plantings reduce their biological stability that is especially noticeable if age of trees more than 50 years.

As a result of the conducted researches it was established that the content of heavy metals on sheet surfaces has ambiguous character and depends on the chemical nature of an element and also on metabolic communications in fabrics of plants.

Wood types on ability of sedimentation of heavy metals on sheet plates form the following row as reduction: Acer platanoides L.> Acer negundo L.> Populus alba L.> Populus * sowietica pyramidalis Jabl>

Robinia pseudoacacia L.> Tilia platyphyllos Scop> Aesculus hippocastanum L.> Fraxinus excelsior L.> Fraxinus lanceolate.

On total accumulation of heavy metals in fabrics of sheet plates, the following number of the types located on decrease of total indicators of accumulation of heavy metals is formed: Populus*sowietica pyramidalis> Populus alba> Quercus robur> Fraxinus excelsior> Aesculus hippocastanum> Robinia pseudoacacia> Acer platanoides> Tilia platyphyllos> Ulmus laevis.

The Coefficient of Biological Absorption (CBA) and coefficient of biogeochemical activity (BHA) allows to judge the general ability of plants to concentration of chemical elements, but at the same time it is necessary to consider age of plantings, the prevailing look and a phase of vegetation.

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Биогеохимическая активность парковых насаждений как индикатор устойчивости древесных растений

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Аннотация

Актуальность исследований связана с повышением устойчивости парковых насаждений Ростовской области, которые имеют историческое значение и природоохранный статус. Проведение многолетнего мониторинга по накоплению тяжелых металлов вносит вклад в установлении биогеохимической роли древесных растений.

Цель исследований – выявление биогеохимической активности парковых насаждений степной зоны на основе изучения видового, возрастного состава древесных растений и коэффициентов биологического поглощения тяжелых металлов.

Коэффициент биологического поглощения (КБП) отражает степень концентрации элемента в растениях по сравнению с сопредельными средами. КБП – отношение содержания элемента в сухом веществе к содержанию в почве, на которой они произрастают. Этот коэффициент характеризует интенсивность извлечения химических элементов из почвы. При этом КБП для каждого элемента во многом определяется как химическими свойствами, так и потребностью растений.

Объекты исследований – парковые насаждения Ростова-на-Дону, Таганрога, Новочеркасска, Азова и Батайска. Они представлены деревьями в возрасте от 40-50 лет (75-80%). Деревья в возрасте более 50 лет (25%) встречаются на территории города Таганрога. На территории парков г. Батайска довольно большой процент насаждений (37) представлен деревьями до 20 лет.

Установлено, что видовой состав парковых насаждений представлен 11 видами (*Quercus robur* L., *Aesculus hippocastanum* L., *Ulmus laevis* Pall, *Fraxinus excelsior* L., *Fraxinus lanceolata* Borkh, *Robinia pseudoacacia* L., *Tilia platyphyllos* Scop, *Acer platanoides* L., *Acer negundo* L., *Populus alba* L., *Populus sowietica pyramidalis* Jabl.) из 8 семейств (*Fagaceae, Hippocastanaceae, Ulmaceae, Oleaceae, Fabaceae, Tiliaceae, Aceraceae, Salicaceae*). Выявлены доминирующие виды в парковых ландшафтах изучаемых городов.

На основе мониторинга парковых ландшафтах города Ростова-на-Дону выявлено, что за вегетационный период в наибольшее количество металлов осаждалось на листовых поверхностях клёна и липы. Избирательность осаждений металлов отдельными видами проявляется в накоплении ими определённых металлов.

На всех изученных объектах (2002-2018 гг.) были рассчитаны суммарные показатели накопления тяжёлых металлов листьями древесных растений. Установлены максимальные коэффициенты биологического поглощения: по Zn (*Populus sowietica pyramidalis*, *Populus alba, Ulmus laevis*); по Cu (*Fraxinus excelsior, Aesculus hippocastanum, Quercus robur*); по Ni (*Acer platanoides, Populus alba, Ulmus*

laevis). Минимальный коэффициент биологического поглощения установлен по Zn и Cu для *Acer negundo*, по Ni - *Tilia platyphyllos*.

Составлен реестр древесных растений по снижению коэффициента биогеохимической активности: *Fraxinus excelsior* = *Populus sowietica pyramidalis* = *Populus alba* (0,4) > *Aesculus hippocastanum* = *Quercus robur* (0,3) > *Acer platanoides* = *Tilia platyphyllos* = *Ulmus laevis* = *Robinia pseudoacacia* (0,2) > *Acer negundo* = *Fraxinus lanceolata* (0,1).

Таким образом, установлено содержание макроэлементов в растениях, которое определяется систематическим положением – семейством, родом и видом. Параметры коэффициентов биологического поглощения, и их динамика в зависимости от времени (например, фазы вегетации), возраста организма, почв рекомендуется использовать в качестве индикаторов устойчивости и подбора ассортимента при реновации исторических парковых ландшафтов.

Ключевые слова

парковые насаждения Ростовской области, степная зона, древесные виды, видовой состав, тяжелые металлы (Zn, Cu, Ni, Pb, Cd), биогеохимическая активность, коэффициент биологического поглощения, индикаторы, устойчивость

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