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DEGRADATION, REHABILITATION, AND CONSERVATION OF SOILS

Anthropogenic Soils of Urban Parks: A Review

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Abstract—Urban parks provide a range of ecosystem services and support a healthy urban environment. Soils are directly involved in biogeochemical cycles and maintenance of biodiversity in parks. The properties of park soils and the modes of their functioning are determined by the interaction of zonal and anthropogenic factors, such as the history of the park, the duration of its existence, ways of soil transformation or technology of soil construction, and the composition of plantations. The soil cover of urban parks is heterogeneous and combines natural and anthropogenic components. Urbostratozems (Urbic Technosols) are common soils of urban parks. The presence of filling material and technogenic inclusions (in particular, construction waste) in these soils leads to the soil alkalization and to heterogeneity of physical and chemical properties in the soil profile. The complexity of the soil cover patterns and the heterogeneity of soil properties in urban parks contribute to an increased diversity of soil microbial communities. Numerous studies demonstrate considerable contamination of the soils of urban parks in Moscow, New York, Shanghai, Beijing, Hong Kong, Madrid, Dublin, and other cities of the world with heavy metals (primarily, Cu, Pb, and Zn) with an excess of their natural background concentrations and national hygienic standards. The content of heavy metals in soils depends on the duration and intensity of anthropogenic impact and varies greatly within each park. Despite a large number of studies on soil pollution, public health risk assessment methods are still under development. The relationships between park soils, vegetation, and soil biota also require further study. The combined study of soils and biological communities in urban parks is a promising area of research that should contribute to the development of measures to maintain the sustainability of urban ecosystems.

Keywords: heavy metals, soil biota, enzymatic activity of soil, urbostratozems, Urbic Technosols

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INTRODUCTION

Since the 1970s, the number of publications on urban soils has been growing continuously. An intensive study of urban soils in the last 20–25 years has resulted in the understanding that these soils perform a wide range of ecological functions: from regulation and purification of surface runoff, maintenance of microclimate, and reduction of air pollution to cultural services [5, 114, 119].

In urban environments, soils under green spaces, in particular, soils of urban parks, function most actively. In a broad sense, a park is a part of urban territory with natural or artificially planted vegetation, with alleys and ponds intended for recreation and walking. A stricter definition is provided by the official GOST (State Standard) 28329-89 [8], according to which a park is a green territory of common use with an area of more than 10 ha, which is an independent object of landscape architecture. The vegetation cover of parks usually combines open spaces with lawns and flower beds and tree plantations, the ratio between which is determined by the architectural solution. The soils of parks are the basis for the sustainable existence of plant communities and the maintenance of biodiversity for a long time [59].

The soil cover of parks is characterized by considerable diversity and complexity depending on the conditions and duration of park formation, the intensity of anthropogenic loads, the initial type of land use, etc.

The aim of this paper is to summarize the results of studies published in the past 20 years on the soils of parks located in cities around the world differing in the time of their foundation and population. Relatively large areas of urban parks, the absence of aboveground and underground infrastructural facilities within their boundaries, and the high ecological significance of the parks make them attractive objects for the study of urban soils as such. Most often, the soils of urban parks are studied not as an independent phenomenon, but in order to solve certain scientific or applied problems—from the assessment of the environmental pollution to the analysis of the biodiversity in the urban environment. The interest of researchers is focused not so much on the morphology and genesis of park soils, as on their functioning and the properties of the surface horizon. The complexity of the object under

† Deceased.

study and the variety of approaches to its study explain the heterogeneity of the published results.

When preparing the article, the search for publications was carried out in the scientific citation databases Web of Science (Core Collection), Scopus, and RSCI. As of February 15, 2021, a keyword search for "urban park soil" yielded 1313 results in the Scopus database and 1339 results in the Web of Science (Core Collection) database, of which only 105 results belonged to the "soil science" category. Materials about the soils of botanical gardens, for which a review was recently published [41], about the soils of linear plantings, roadside lanes, boulevards, etc., as well as about sealed soils, were excluded from the search results as not directly related to parks.

SOILS OF PARKS IN RUSSIAN AND INTERNATIONAL CLASSIFICATION SYSTEMS

The problem of classification is traditionally considered one of the most controversial in soil science and is solved in different national and international systems in different ways. The first classification decisions for urban soils were proposed by European researchers [44, 71]. More detailed discussion of the approaches towards the systematics and classification of urban soils in different countries can be found in a number of publications [48, 54, 62, 65, 74, 85].

Russian classification. In Russia, the systematics of urban soils has been developed by Stroganova with coauthors since the mid-1980s [6, 37, 38]. According to Stroganova, most of the anthropogenic soils of urban parks belong to urban soils proper (urbanozems) and agrourbanozems (culturozems). Urbanozems are specified by the absence of natural genetic soil horizons to a depth of 50 cm and by the presence of one or more specific urbic horizons (**U**) instead of them. Culturozems are characterized by a considerable thickness of the humus horizon, the presence of mucky–compost–peat surface layers with a thickness of more than 50 cm, which are underlain by the lower part of the profile of the former native soil, or by the cultural layer (habitation deposits), or by various substrates.

Initially, the systematics of urban soils according to Stroganova and according to the *Classification and Diagnostic System of Russian Soils* (**CDSRS**, 2004) [13] existed independently. In the CDSRS, typical urban soils were separated into a group of technogenic surface formations (**TSFs**) as urbiquasizems (urban quasi-soils). Subsequently, Prokof'eva with coauthors initiated work on the full inclusion of urban soils (originally, Moscow soils) as soils proper, but not TSFs, into the CDSRS [27]. At the next stage, approaches to the systematics and diagnostics of urban soils within the framework of CDSRS were worked out and agreed already on the scale of Russia [25]. According to [25], anthropogenic soils of urban parks, depending on their characteristics, belong either to the order of Agrozems in the trunk of postlithogenic soils, or to the order of Stratozems in the trunk of synlithogenic soils. In the order of Stratozems, three types of urbostratozems (urbanozems) have been separated: typical urbostratozems (UR–D), urbostratozems on buried soils (UR–[A–B–C]), and technogenic urbostratozems (UR–TCH, UR–TCH–D). The urbic horizon (UR) is a surface horizon in an urban environment, grayish brown in color, silty, containing more than 10% of artifacts (mainly, construction debris and household waste) and having a thickness of more than 5 cm, if underlain by the cut natural substrates or technogenic deposits; or at least 40 cm, if it is underlain by natural soil horizons with a smooth and abrupt or clear upper boundary. Also, the urbic horizon has one or more of the following features: layered composition, sandy and/or gravelly texture, neutral to alkaline reaction (often, effervescence from HCl), presence of pollutants in concentrations of no more than 2 MPC (APC) (maximum/approximate (provisional) permissible concentration), and an increased phosphorus content (but no more than 100–200 mg/kg for available phosphorus or 0.2% for total phosphorus).

An original approach to the classification of urban soils, including park soils, was proposed by Aparin and Sukhacheva [2]. Owing to the fact that urban soils suitable for green plantations are usually created via application of filled (introduced) humus horizon, the authors suggested that a separate order of introduced soils (filled soils) should be categorized within the trunk of synlithogenic soils. Introduced gray-humus or dark-humus horizons were designated as RY and RU horizons; introduced peat horizon was designated as RT horizon. Such horizons should have a thickness of more than 40 cm and be underlain by the mineral substrate (D) formed in situ or introduced from outside. In a later publication [3], the introduced (filled) horizons were named as pedo-allochthonous horizons with their subdivision into the ALY (pedo-allochthonous gray-humus horizon), ALU (pedo-allochthonous dark-humus horizon, ALT (pedo- allochthonous peat horizons, and ALTR (pedo-allochthonous peat–mineral horizon).

The classification of urban soils continues to be updated, as does the CDSRS in general [26].

International classification. In the international WRB system [80], anthropogenic soils of parks, depending on their characteristics, can be assigned to one of the two reference groups: Technosols (Urban Technosols) or Anthrosols (Hortic Anthrosols or Terric Anthrosols). The Urbic qualifier implies the presence of a layer with a thickness of 20 cm or more containing ≥20% (by volume) of artifacts with 35% or more (by volume) of rubble and refuse of human settlements within the top meter of the soil. The group of Anthrosols includes cultivated soils with a thick humus horizon and with a small amount of anthropogenic inclusions. In *Soil Taxonomy* [62], urban soils are considered as human-altered human-transported (HAHT) soils.

MORPHOLOGICAL FEATURES OF PARK SOILS

The profile of urban soils includes a series of filled layers varying in their composition and thickness in dependence on the source of allochthonous material and the nature of land use (in parks, in dependence on the park planning, presence of buildings, and diversity of plantings) [48, 77]. The thickness of the filled layer may depend on the location of the park. For example, in St. Petersburg, in suburban parks and in new parks on the urban periphery, it is smaller than in the historical parks in the central part of the city (Fig. 1) [22, 94]. In some cases, buried horizons and soils lie under the anthropogenic layer in parks [21, 22, 24, 77].

The analysis of publications showed that anthropogenic soils of parks are formed on different substrates of natural and technogenic origins. Zonal soils or local soil-forming rocks can form the base of park soils; the anthropogenic layer covering them is created purposefully to improve soil properties and increase soil fertility, or it gradually evolves in the course of the long-term land use with the formation of cultural layer. The expansion of areas under green plantations in densely built-up areas of cities, where natural soils have not been preserved, requires the "import" of fertile soil material, which has to be withdrawn from adjacent non-urbanized territories. To avoid this, research is being conducted in the field of artificial soil construction for the needs of urban landscaping. The components of such constructions are local sediments extracted during construction works, composts from organic waste, and/or crushed concrete or bricks [35, 57, 106, 115].

Urban development expands due to the newly created areas with filled sediments; in a few instances, new city parks appear on them (for example, the 300th Anniversary of St. Petersburg Park). In terms of the morphology and functioning of these artificially created filled soils, they differ both from the natural soils of the region and from typical urban soils [91]. As a result, the technology of soil filling (by alluviation) is characterized by a high content of clay and an increased bulk density, which prevents the development of root systems of trees outside the planting pit and contributes to the stagnation of rainwater and the development of gleyzation.

In the morphological structure of the soils of parks, the memory of the past stages of land use is preserved for a long time. At the same time, each type of anthropogenic transformation corresponds to a specific horizon or a series of horizons that are formed in the course of sedimentation (synlithogenic horizons) or constructed on the surface of an urbopedosediment

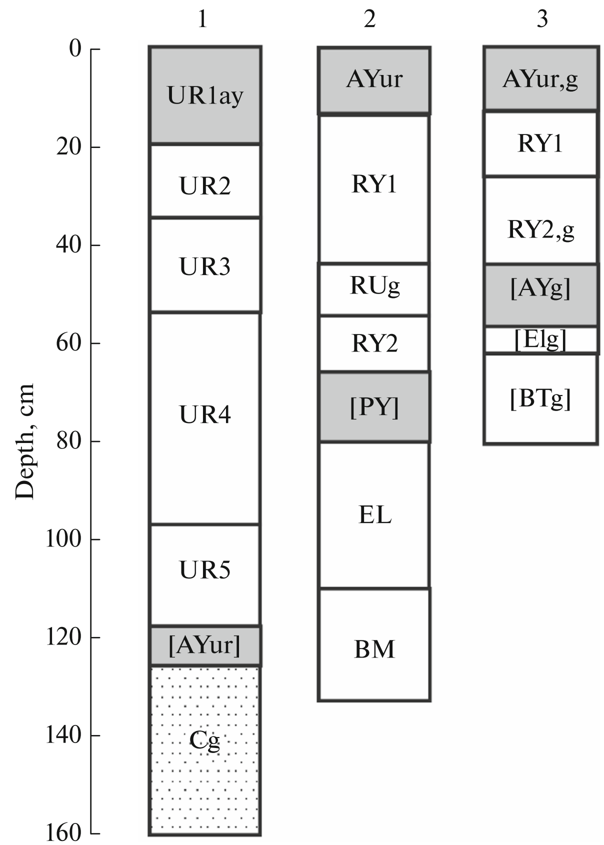

Fig. 1. Horizonation of soil profiles in the parks of St. Petersburg: (1) gray-humus urbostratozem on buried gleyic gray-humus soil (Summer Garden) [21], (2) thin gray-humus urbostratozem on buried postagrogenic soddy eluvial-metamorphic soil (Internationalists Park, Frunzensky district) [22], and (3) gray-humus urbostratozem on buried gleyic soddy-podzolic soil developed from moraine loam (park of the Petergof Museum-Reserve) [18].

[28, 82]. Major historical events are reflected in the soils. A striking example is the Teufelsberg Park created on an artificial hill in Berlin. The hill is made up of the fragments of many buildings destroyed by bombing [119].

SOIL COVER OF PARKS

The soil cover of cities is characterized by mosaic patterns, which is associated with spatial proximity and alternation of different types of land use within the same area [58, 103]. Mapping of the soil cover of individual parks is carried out mainly by Russian researchers, who have shown that the proportion of anthropogenic soils in parks can vary widely. When a park is created in a natural landscape with the absence of soil disturbances inherited from past stages of land use, the purposeful transformation of the original soil cover is associated with the planting of decorative plantations, reclamation measures, the creation of canals and ponds, the laying of footpaths, as well as with the construction of palace and park facilities. In this case, knowledge of the layout and history of the formation of the park allows us to predict the localization of anthropogenic soils within its territory.

The absence of natural soils is typical for small parks located in the city center and surrounded by high-density development. A typical example of such a park is the Summer Garden [21], the soil cover of which consists exclusively of urbostratozems. Similarly, in the Vorob'evy Gory Park in the central part of Moscow, anthropogenic and anthropogenic-transformed soils occupy more than 90% of the territory [23].

The soil cover of large parks located in the periphery of the city or in the suburbs includes both anthropogenic and natural soils. For example, in Petergof parks, the proportion of stratozems and urbostratozems varies from 5 to 40% or more; in different landscape areas of the Pavlovsk Park, from 10 to 83%, depending on the history and layout of the park [18–20]. Anthropogenic soils tend to occur in the areas around park constructions and areas with a regular layout (Fig. 2). At the same time, the natural specificity of park territory is reflected not only in the spectrum of natural components of the soil cover but also in the processes that occur in anthropogenic soils and lead to the appearance of new soil types and subtypes; thus, the development of gley processes leads to the appearance of gleyic and gleyed urbostratozems (Fig. 3).

Natural soils are mainly preserved in the areas of natural landscapes included in the park layout in a slightly transformed form [19, 20]. In the natural-historical parks of Moscow located on the periphery of the city (Pokrovskoe-Streshnevo, Tushino, Izmailovo, Tsaritsyno parks), the share of natural soils is 31–63% [17]. The combination of anthropogenic and natural soils in the soil cover of urban parks was also revealed in the parks of Kaliningrad [1] and Vladivostok [11].

The differentiation of the soil cover in those areas of parks, where it retains its original pattern or has been changed to a minor extent, is determined by natural factors (topography, soil-forming rocks, the level of groundwater). Thus, in one of the parks of Petergof—the Sergievka Park—the diversity of natural soils is determined by the topography (flat areas, closed depressions, steep slopes of the ravine) and soil-forming rocks (glaciolacustrine sands, moraine loams, colluvial deposits). On the Pridvortsovyi plot of the Slavyanka River valley area in the Pavlovsk Park, natural soils replace one another along the catena from the local divide towards the riverbed.

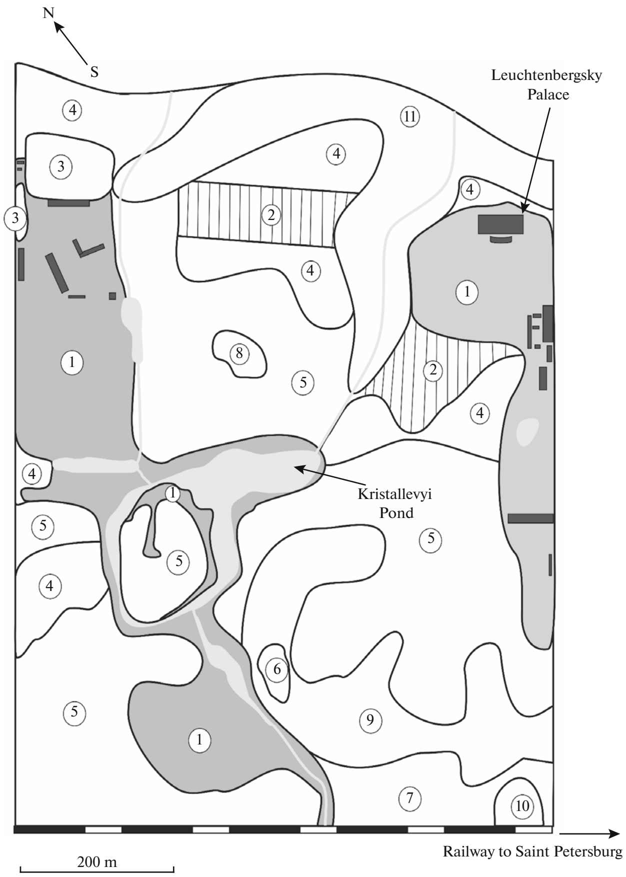

Fig. 2. The soil cover of the Sergievka Park (Petergof) [18]. Soils: (1) gray-humus urbostratozems on different rocks, (2) stratified soddy-podzolic soils on moraine loams, (3) postagrogenic agrozems on moraine loams, (4) typical soddy-podzolic soils on moraine loams, (5) gleyic soddy-podzolic soils on moraine loams, (6) gleyed soddy-podzolic soils on moraine loams, (7) mucky-podzolic gley soils on moraine loams, (8) soddy iron-illuvial podzols on glaciolacustrine sands underlain by moraine loams, (9) gleyic soddy podzols on glaciolacustrine sands underlain by moraine loams, (10) peat gleyzems on moraine loams, and (11) combination of eroded and aggraded soddy soils on colluvial sediments.

PROPERTIES OF PARK SOILS

The properties of anthropogenic soils of parks are basically similar to the properties of other urban soils. Changes in physicochemical characteristics in comparison with zonal soils, as a rule, consist of an increase in pH [85]. The following pattern appears: strongly transformed soils with inclusions of construction debris have an alkaline reaction, and the reaction of natural and poorly transformed soils varies from acid to slightly acid and neutral (Table 1) [67, 77, 85]. Soil alkalization can play a negative role reducing the availability of phosphorus and microelements for plants [83].

The upper horizons of urban soils are generally characterized by an increased content of nutrients, especially phosphorus, caused by their supply from a variety of anthropogenic sources [83, 100]. In parks, such transformation of soil chemical characteristics can be facilitated by landscape works (terrain planing,

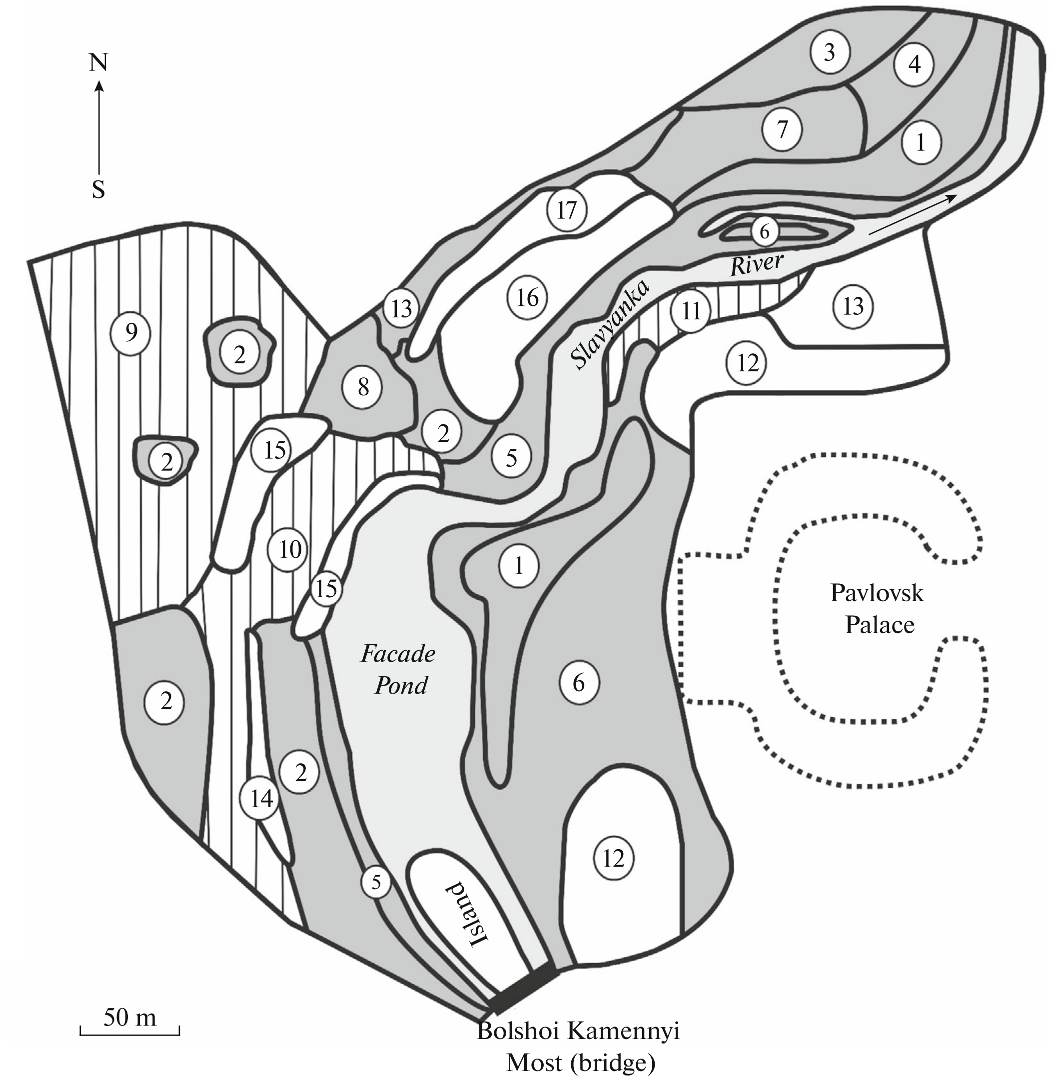

Fig. 3. Soil cover of the Pridvortsovyi plot of the Slavyanka River Valley area in the Pavlovsk Park [19]. Soils: (1) loamy sandy gray-humus stratozem on alluvial deposits, (2) loamy sandy gray-humus stratozem on buried soil, (3) sandy loamy gleyic gray-humus stratozem on clay, (4) sandy loamy gleyic gray-humus stratozem on glaciolacustrine sediments, (5) eroded loamy sandy gleyic gray-humus stratozem underlain by Cambrian clay, (6) loamy sandy gray-humus urbostratozem underlain by varved clay, (7) sandy loamy gleyic gray-humus urbostratozem on varved clay, (8) sandy loamy gleyic gray-humus urbostratozem on glaciolacustrine sands, (9) loamy sandy stratified turbated iron-illuvial soddy podzol on glaciolacustrine sediments, (10) loamy sandy stratified gray-humus soil on glaciolacustrine sediments, (11) loamy sandy gleyic gray-humus soil on sands underlain by loam, (12) loamy sandy typical gray-humus soil on glaciolacustrine sediments, (13) aggraded sandy loamy dark-humus soil on glaciolacustrine sediments, (14) aggraded silt loamy dark-humus gleyed soil on alluvial sediments, (15) mucky gley soil on alluvial sands, (16) peat gleyzem on oxbow alluvial sediments, and (17) peat soil.

replacement of surface horizons of natural soils with allochthonous material, regular application of mineral and organic fertilizers) [73, 110]. For example, the content of total phosphorus in the soils of old parks in Helsinki (Finland) exceeds that in forest soils by more than two times [112].

At the same time, in conditions of rare soil cultivation activities and the absence of pollution, an increased pH level and a high phosphorus content may not be detected even in the soils of parks located in the historical centers of large cities. Thus, in London, against the background of high phosphorus content in the soils of the city center, Hyde Park and the adjacent Kensington Gardens, Green Park and St. James's Park stand out as a "cold spot" [95]. The availability of potassium in the soils of parks can vary significantly, which is shown by the examples of parks in St. Petersburg and the suburbs: the Summer Garden [12], the Quiet Rest Park, and the Babolovskii Park [14]; the Gatchina Palace Park [24].

The soils of parks are usually characterized by an increased content of organic carbon (humus) in the

Table 1. pH of water extract in park soils

City, park	pH_{water}	Object characteristics	Reference
Soundview Park, New-York	7.0–7.7	Urbic Technosol	[77]
Parks of Foshan, China	4.1–4.7	Weakly transformed soils	[73]
	5.4–7.1	Strongly transformed soils	
Pokrovskoe-Streshnevo Park, Moscow	7.0–8.1 5.2–6.4	Urbanozems Rzhavozems	[28] [17]
Tushinskii Park, Moscow	6.4–7.5 3.9–5.3	Urbanozems Soddy-podzolic soils	[17, 29]
Parks of Zielona Gora, Poland	3.5–7.5 (mean 6.4 ± 0.9)	Natural and anthropogenic soils	[66]
Parks of Anji, China	7.1–7.9	Layer 0–10 cm	[121]
Parks of Sopron, Hungary	7.7–7.9	Layer 0–10 cm	[72]
Former Imperial Residence Park (Shrogane-goryouchi), Tokyo, Japan	4.5–6.2	Different soils	[82]
Planty Park, Krakow, Poland	7.0–7.7	Anthropogenic soils	[64]
Summer Garden, Saint Petersburg	5.8–7.4	0–20 cm	[12, 21]
	6.2–8.6	Filled mass	
Lužánky Park, Brno, Czech Republic	7.08 (mean)	Layer 0–5 cm	[47]
Park of the 300th Anniversary of St. Petersburg, St. Petersburg	6.2–7.9	Urbic Technosol on alluvial soils	[104]
Palace Park, Gatchina	6.4–7.8	Urbanozems	[24]
Pavlovsky Park, St. Petersburg	4.9–7.8, 6.2 (median)	Stratozems and urbanozems	[94]

upper horizons (up to 5–8% or more) [14, 24] and, in some cases, in deeper horizons [77]. In the latter case, this is due to the presence of buried humus horizons of natural or anthropogenic origin. The carbon content depends on the zonal and climatic conditions: for example, in the parks of Torun (Poland) with a temperate climate, its content in soils was is three times higher than in the parks of Marrakech with a Mediterranean climate [42].

Not only the content of humus but also its distribution and composition change in the soils of parks in comparison with natural soils. Dolotov and Ponomareva [9] noted that the filled mass in the Summer Garden acquired features of the soils of broadleaved forests (gray forest soils) in terms of humus distribution in the soil profile and of brown forest soils (burozems) in terms of the group composition of humus. The content and distribution of humus in the soils of parks are affected by the nature of plantings and their management features. As shown by Gorbov and Bezuglova [7], the humus content in the surface layer of soils under the layer of lead litter in forest parks of Rostov-on-Don is about two times higher than that in the zonal chernozems, and the distribution of humus in the profile of park soils acquires the features typical of forest pedogenesis.

The maintenance of the soil carbon stock makes a critical contribution to the regulation of climate change [98]. In this context, increased attention is paid to the carbon budget of urban soils. In Milan (Italy), a study of surface (0–10, 10–20 and 20–40 cm) soil horizons revealed that carbon stocks in the soils of parks (7.9 ± 2.4 kg/m2) are comparable with those in forest soils and exceed not only the values typical of other urban soils (soils of public gardens, landscaped streets, vacant lots (5.3 ± 2.5 kg/m^2)), but also of arable soils of the region [50]. In the soils of parks and protected natural plantings of Anji (China), the organic matter content turned out to be significantly higher compared to the soils under street green spaces and plantings adjacent to industrial and residential buildings [121].

POLLUTION OF PARK SOILS AND METHODS OF ITS ASSESSMENT

The problem of technogenic pollution with heavy metals (**HMs**) has always been in the limelight when studying urban soils [37, 48]. The so-called urban metals—Pb, Cu, Zn, and some others—are best studied among the HMs [52, 90]. Their increased contents are observed in most of the urban soils. Most publications consider the content and spatial distribution of HMs in the surface horizons of soils and their danger is assessed from the point of view of sanitary-epidemiological and environmental standards [31].

The main sources of HMs in urban soils are emissions from motor vehicles and industry, construction debris, and other technogenic wastes. Imported soils and fertilizers can be additional sources of soil pollution in parks.

Soil contamination with HMs due to vehicle emissions was recorded in most of the studied urban parks [18, 40, 64, 72, 76, 116]. At the same time, the impact of urban transport may be local in nature and not extend to the park as a whole. Thus, in the surface (0–10 cm) soil horizons of the Phoenix Park (Dublin, Ireland), an increased content of Pb, Cu, and Zn was observed within 40-m-wide land strip along the road [56]. A large (20 ha) Lužánky Park (Brno)—the first public park in the Czech Republic created in 1786–1787—is located in close proximity to roads with heavy traffic. However, only relatively small soil contamination with Zn, Cd, Cu, and Pb has been determined in the surface horizons of the soils of this park, which does not pose a risk to the health of the population, including children. The most polluted areas are those along the borders of the park [47]. The role of Pb in the pollution of urban soils has been declining in the recent decades because of the refusal of most countries from the use of leaded gasoline containing tetraethyllead as a fuel. Therefore, no lead accumulation is observed in the soils of recently created parks [76, 112].

A number of authors claim that pollution inside the city is usually differentiated by land use zones, and the soils of parks, especially in the periphery of the city, are less contaminated with HMs than the soils of residential and commercial zones and, especially, the soils of industrial zones and transport zones with heavy traffic [78, 88, 101]. This pattern was well demonstrated by the study of soils of urban, suburban, and countryside (rural) parks in Hong Kong [84] (Table 2). It was found that the soils of urban and suburban parks are characterized by significantly higher contamination with HMs than the soils of parks in rural areas. At the same time, the soils of urban parks densely surrounded by buildings are characterized by stronger contamination than the soils in the suburbs. Cluster analysis and principal component analysis showed the difference between the associations of elements in the soils of rural and urban parks. In the first case, HMs are associated with macronutrients (Al, Fe) in the composition of natural rocks. In the second case, the technogenic input of elements such as Cd, Cr, Cu, Ni, Pb, and Zn is clearly manifested.

The contents of HMs in the soils of parks do not necessarily follow the urbanization gradient based on the modern nature of land use and vegetation cover, which, to a greater extent, reflects a long history (type, degree, and age of anthropogenic disturbances). High concentrations of HMs can be observed not only in the surface but also in the deeper horizons of anthropogenic soils corresponding to past periods of land use [55, 77, 89, 93]. The study of the total content of five potentially toxic elements (Cr, Ni, Pb, Zn, Cu) in the surface soil horizons of parks in six European cities, different in climate and geological structure and with different histories, performed using the same methodology [90], allowed us to conclude that the degree of urbanization (age of the city and park, industrial load, population, etc.) is the main factor determining the concentrations of Pb, Zn, and Cu in soils. The maximum contents of HMs were found in two parks (Glasgow Green and Alexandra Park) in Glasgow (Great Britain) and in the Valentino Park in Turin (Italy), which are the oldest parks in the cities with a high population and a long history of heavy industry development. On the contrary, in the smallest city (Aveiro, Portugal), in the Galitos Park founded less than a decade ago, HM concentrations were the lowest. In the parks of three other cities—Uppsala (Sweden), Seville (Spain), and Ljubljana (Slovenia)—HM concentrations had intermediate values. Various ways of soil contamination with HMs (Cd, Cu, Pb, and Zn) have been established for the Planty Park surrounding the Old Town in Krakow (Poland): from medieval metallurgy to modern industrial and transport emissions, as well as coal burning [64]. The history of land use has also influenced the distribution of HMs in Robertson Park (Perth, Australia) [109]. Increased concentrations of Pb were detected in the part of the park, where the glass factory and its waste dump were located in the 1920s–1970s. The accumulation of elements that are part of building materials and/or related to industrial activities (Fe, Zn, Cu, Ni, and Mo) has also been discovered in the same area. The role of various technogenic sources in the specificity of HM accumulation in the soils of urban parks is considered by the example of the Czech cities of Prague (with the maximum population) and Ostrava (with developed heavy industry). It was found that the soils of Ostrava are more polluted with Zn and Cd, and the soils of Prague are more polluted with Pb and platinum group metals. The main sources of HM pollution in Prague are vehicle emissions and brown coal burning and in Ostrava, coal processing and metallurgical industry [63, 96].

The distribution of HMs in the soils of parks is also affected by vegetation cover, which was shown by the study of the upper 50-cm soil layer in 41 parks of various ages in Helsinki (Finland) and in 5 control forests [112]. The soils of open meadow areas were generally characterized by higher contents of HMs (Cr, Mn, Fe, Ni, Cu, and Zn). This phenomenon was often observed in young and, partly, middle-aged parks. The content of all metals was lower in soils under deciduous trees in young parks and under evergreens in older parks. The stocks of HMs in the soils of old parks were higher than in the soils of control forests.

The greatest concern of researchers is the possible risk to public health associated with the carcinogenic

Table 2. Total contents of heavy metals (range of values, median in parentheses) in the soils of parks in different cities of the world

City, parks (number)	Content of elements, mg/kg soil			Reference
	Cu	Pb	Zn	
Soundview Park, New York	48–529	160–1049	184–792	[77]
New York City Parks (Central, Pelham Bay Park, Van Cortland Park)	14–138 (46)	40–730 (178)	19–300 (81)	[49]
City Parks of Hong Kong (China)	1.3–277 (10.4)	7.5–496 (70.6)	23.0–930 (78.1)	
Suburban parks of Hong Kong (China)	1.39–89 (4.9)	15.8–161 (49.4)	25.5–173 (52)	[84]
Rural parks of Hong Kong (China)	2.0–20 (4.8)	11.2–124 (36.5)	25.3–136 (43.6)	
Parks (28) of Guangzhou (China)	59.8	107.9	91.7	[68]
Phoenix Park, Dublin, Ireland	25	39	94	[56]
Parks (9) in Ostrava, Czech Republic	18–175 (38)	27–125 (49)	78–922 (151)	[63]
Parks (13) Prague, Czech Republic	16–114 (54)	22–213 (62)	57–285 (122)	[63]
Parks and green areas of Prague, Czech Republic	47.1	72.5	145	[105]
Parks of Katowice, Poland	30	270	590	
Parks of Zabrze, Poland	13.5	67.5	250	
Parks of Dabrowa Gornicza, Poland	21.0	270.0	660.0	[87]
Parks of Tarnowskie Gory, Poland	22.0	930.00	1390.0	
Parks (100) of Los Angeles	Not det.	45.0	Not det.	[76]
Galitos Park, Aveiro, Portugal	8–61 (16)	7–38 (20)	18–82 (49)	
Glasgow Green Park, Glasgow (Great Britain)	24–113 (88)	98–676 (279)	102–377 (174)	
Alexandra Park, Glasgow, United Kingdom	33–113 (59)	114–414 (179)	67–305 (104)	
Tivoli Park, Ljubljana, Slovenia	21–78 (31)	39–225 (72)	84–300 (103)	[90]
Los Principes Park, Seville (Spain)	30–72 (47)	43–247 (100)	73–191 (99)	
Valentino Park, Turin, Italy	44–123 (83)	68–257 (137)	116–317 (234)	
Stadsträdgården. Uppsala, Sweden	8–90 (31)	7–116 (36)	27–193 (106)	

and toxic effects of pollutants. In China, the carcinogenic and non-carcinogenic risk of HM (Cd, Co, Cr, Cu, Mn, Ni, Pb, Zn) impact on human health was assessed for 40 surface horizons of soils from open lawns in 14 parks of Xiamen [88] and for 28 parks of Guangzhou (the main industrial and economic center and the largest city in southern China, with a population of about 10 million people) [68]. The authors determined the concentration of compounds that penetrate into the human body during peroral admission. In order to solve the latter problem, SBET (simple bioavailability extraction test) was used (extraction at a temperature of 37°C for 1 h with 0.4 M glycine solution brought to pH 1.5 using concentrated hydrochloric acid (soil : solution ratio 1 : 100). The total content of HMs in some places exceeded the permissible levels, but their bioavailable concentrations were not always high, which was due to the characteristics of particular metals and the properties of the soil matrix. The authors of this study emphasized the need to take into account the type of land use and bioavailability of HM compounds when assessing the risk to human health. As has already been intimated, the results of the bioavailability assessment certainly depend on the chosen method of analysis. Chemical fractionation of HMs (according to the BCR scheme) carried out in Xiamen for the surface (0–10 cm) soil horizons [125] attested to the predominance of bioavailable fraction discovered by this method for Cd (82.0%), Cu (58.5%), Mn (58.4%), Zn (57.6%), Co (55.4%), and Pb (50.3%). Principle component analysis and multiple linear regression allowed us to establish that anthropogenic sources are the main contributors to the bioavailable fraction of most of HMs, except for Cr and Ni.

Organisms dwelling in polluted soil come into the closest contact with it. Data on the influence of HMs on the soil microbiota are ambiguous. For the soils of the city park in Aberdeen (Scotland, UK), a negative correlation of the value of microbial biomass with the total lead content and with the content of its mobile forms was shown [123]. During the study of the soils of the garden of the Royal Palace in Naples (Italy), significant negative correlations were revealed between the increased content of HMs (Cu, Cd, V, Pb) and the microbiological parameters (microbial biomass, basal respiration, and the activity of a number of enzymes (cellulase, protease, and invertase) [102]. The negative impact of pollution on the microbiological properties of soils and related ecological functions was also demonstrated by other researchers [111].

A comparative study of the surface horizons (0–15 cm) of the soils of the historical parks of Marrakech (Morocco) and Torun (Poland) revealed that HMs, even in relatively low concentrations, can be inhibitors of many enzymes in the soil [42]. However, alkaline phosphatase and urease were less sensitive to anthropogenic impact than dehydrogenase. A significant inhibition of the activity of dehydrogenase with an increase in the anthropogenic loads (building activity, traffic, HM pollution) was also observed in another study of the soils of Marrakech [99], as well as in the study of 12 urban parks in Upper Silesia [43].

An unexpected result was obtained when studying the enzymatic activity of the soils of Liberty State Park in New York (USA), created in 1970 on the site of a landfill of construction and household garbage [69]. The study was conducted on the only non-reclaimed area of the park with a high level of pollution, under a deciduous forest with a grassy ground cover. The total As content in the soils of this area was 5–20 times higher than the background value (up to 31.73 mg/kg); the total Pb content, 10–20 times higher (up to 414.71 mg/kg), and the total Zn content, 2–3 times higher (up to 140.69 mg/kg). The enzymatic activity was found to be highest at the most polluted of the four surveyed points, where, in addition to the listed elements, high concentrations of Cr (96.37 mg/kg) and V (137.29 mg/kg) were observed, with which the studied enzymes revealed the strongest positive correlation. The authors explain the paradoxical results by the fact that the activity was determined in the soils that had been undisturbed by humans for more than 40 years, so that natural succession occurred, which contributed to the development of the functioning capacity of enzymes under the extreme environmental conditions.

In addition to HMs, organic compounds (primarily, polycyclic aromatic hydrocarbons (**PAHs**)) emitted during combustion of fossil fuels (coal, gasoline, diesel fuel), and deicing mixtures that provoke salinization and changes in the physicochemical characteristics of soils, are common pollutants of urban park soils. The spatial distribution of PAHs in urban soils is characterized by the same patterns as for HMs. Thus, the PAH content in the soils of Beijing parks [107] was affected by the length of roads and the level of coal consumption in the part of the city, in which a given park was located, as well as by the distance from the city center and the age and area of the park. The total PAH content in the studied soils on the territory of 122 parks varied in the range of 0.066–6.867 mg/kg (average 0.460 mg/kg). At the same time, seven carcinogenic PAHs accounted for 47% of the total concentration of these compounds in soils. The molecular composition of PAHs (a significant predominance of 4–6-membered PAHs over 2–3-membered PAHs) attested to their formation as a result of high-temperature combustion of various types of fossil fuels (coal, gasoline, diesel fuel). In general, the content of PAHs in almost all of the studied soils of Beijing parks was assessed by the authors of the paper as acceptable according to the sanitary-hygienic and environmental criteria.

Soil contamination with PAHs, especially high-molecular-weight PAHs, was also noted in some parks in Stockholm [61]. The authors investigated the surface horizons in 25 parks of the city. Using diagnostic relations and positive matrix factorization, the authors found that PAHs in soils have a pyrogenic origin associated with automobile emissions and biomass combustion.

SOIL BIOTA OF URBAN PARKS

Invertebrate fauna. If the fauna of urban parks is more or less studied, the investigation of invertebrates living in soils is only at the beginning of its development. Research on this topic is being conducted mainly abroad (in USA, Italy, Spain, France). The criteria for the selection of organisms for study are the widespread distribution and sensitivity to changes in soil conditions and the ecological situation as a whole. In addition, ecosystem engineers actively transforming their habitat [81] that include earthworms and ants among the soil fauna, are of significant interest.

Earthworms, with their well-known impact on soil properties (forming of structure, enrichment with organic matter, loosening, etc.) and significant biomass per unit area, became one of the first objects of research. A comparative study of earthworm populations in three urban parks older than 75 years and lawns of different ages (older than 75 and younger than three years) in a residential area of Moscow (Idaho, USA) [113] showed that the soils of parks are characterized by the highest density of earthworms (437 individuals/m^2). It was almost four times lower (121 individuals/m^2) in the soils of old lawns, and the lowest was in the soils of young lawns (26 individuals/m^2). The live weight of worms at these sites was 94.12 g/m^2, 28.08 g/m^2 and 4.69 g/m^2, respectively. Herbaceous vegetation everywhere was represented by grasses (*Poa pratensis*), tree plantations in the park were represented by maple (*Acer platanoides*). The litter layer on the surface young lawns was absent; in the parks, it reached 5 cm. Carbon and nitrogen reserves in the upper 30-cm-thick soil layer were the highest in the parks (3.6 and 0.26 kg/m^2, respectively) and the lowest in the soils of young lawns (1.4 and 0.10 kg/m^2); the soils of old-age lawns occupied an intermediate position. The authors explained the low abundance of earthworms in the soils of young lawns by insufficient time for colonization of these soils by the earthworms from neighboring plots, and the inability of the soil to provide suitable habitats, in particular, due to an increased bulk density (1.6–1.7 g/cm^3 compared with 1.3 g/cm^3 in the park soils). Such a high density, which is not inherent in the soils of not only parks, but also old lawns, is associated with the use of modern construction technologies that have a more destructive effect on soils. Among the earthworm species at all the plots, there were no native species, which, apparently disappeared during the period of anthropogenic soil disturbances, and the soil was populated with *Lumbricus terrestris, L. rubellus, Aporrectodea trapezoides, A. longa* instead—exotic alien species for North America [70]. The maximum diversity of earthworms was found in the soils of the parks. The authors explained this by a higher content of organic matter in these soils, which contributes to a better provision of earthworms with food resources and improves soil conditions. The favorable soil moisture regime, which develops in parks due to regular (once per 7–10 days) watering, also matters.

Despite the fact that in the small parks of Moscow (Russia), located in the city center, the composition of the mesofauna is the poorest, the proportion of earthworms in the mesofauna increases, and their abundance in many cases exceeds the abundance of earthworms in the parks at the outskirts of the city [30]. The reduction in the diversity of mesofauna in the parks of the city center is caused not only by the high anthropogenic burden on the soils but also by their isolation from natural communities, which prevents the settling of local fauna species in the central parks.

When creating new parks on constructed soils, the main role in the distribution and species diversity of invertebrates is played by the presence and properties of the filled upper fertile layer. Communities of ants and earthworms in surface horizons (0–15 cm) on lawns with grassy cover were studied in the constructed soils (Technosols) of the parks of the Seine-Saint-Denis and Val-de-Marne departments in the vicinity of Paris (France) [115]. Soils aged from 2 to 64 years were studied (12 soils with an initially created filled upper horizon and 8 soils without it). All the studied soils were similar in most characteristics, including soil texture; pH; cation exchange capacity; and the contents of P, K, and HMs. The density of earthworms in them varied from 0 to 171 individuals/m^2 (average 93.4 individuals/m^2). As the soil age increased, the density of earthworm communities and the prevalence of ants increased in the group of soils with the initially created humus horizon. Whereas in the group of soils without a humus horizon, a decrease in both indicators was observed. Communities of earthworms and ants in the studied soils were represented by several generalist species, which is typical for an urbanized environment. The predominant worm species were *Lumbricus castaneus, L. terrestris, Aporrectodea caliginosa, and Allobophora chlorotica;* the omnivorous *Lasius niger,* and, to a lesser extent, *L. flavus* predominated among the ants. These species are considered as species that benefit from proximity to humans. In an earlier study conducted in 24 parks in Cordoba and Seville (Spain), it was also noted that synanthropic and/or exotic species predominate among ants [51].

Invertebrates can be indicators of changes in soil formation processes in urban conditions. Thus, the predominance of phytophages and predators and a small number of saprophages among representatives of the coleoptera fauna (ground beetles) in the soils of four city parks of Rostov-on-Don indicates a slow process of humus formation [33].

Collembolans can be considered indicators of biodiversity in the soils of urban parks, since they occur in a wide range of environmental conditions, and many soil characteristics are key to the survival of these organisms. A study of eight parks of different ages in Naples (Italy) [97] has shown that the presence of a tree canopy and a layer of litter on the soil surface are the key factors contributing to the diversity of collembolans in urban soils, obviously due to the provision of food resources and the creation of spatial niches.

Microbiota. The diversity of microorganisms and their activity are recognized as one of the most important biological characteristics of the soil [16, 39]. The microbiota of urban soils is being actively studied all over the world. Traditional methods of cultivation on nutrient media in the study of microorganisms in soils are being replaced by more modern molecular genetic methods [32, 45, 92], which made it possible, for example, to identify in the soils of New York City parks a high diversity of microbial communities and clusters of genes encoding biologically active compounds suitable for use in medicine (such as antibiotics erythromycin, nystatin, rifamycin, etc.) [53, 108].

The complex component composition of the soil cover of many parks and the simultaneous presence of soils with varying degrees of anthropogenic transformation create a wider range of environmental conditions and thus contribute to an increase in the diversity of bacterial communities. In Lahti and Helsinki (Finland), the abundance and diversity of bacteria and fungi were higher in parks than in the control forests with which the comparison was carried out [75]. In the anthropogenic soils of New York parks [77], less common bacterial taxa were present compared to those in the slightly transformed urban soils. In cities of different natural zones of Russia (Nadym, Yaroslavl, Moscow, Chelyabinsk, Kursk, Sochi), the density of prokaryotes in the soils of parks is 1.3–2.5 times greater than their average natural density. Moreover, the abundance of microorganisms in the soils of residential and residential–transport urban landscapes may be even greater than in the soils of parks [36].

The diversity of algae in the soils of parks may remain at the level of zonal soils [15] or increase due to a wide range of anthropogenic impacts, similar to the diversity of bacteria. Thus, a study conducted by Dorokhova [60] showed that communities of algae and cyanobacteria in a slightly human-modified soil of the park in Moscow have similarities with those in the background area under the forest. At the same time, anthropogenic impacts (changes in the vegetation cover, which cause a large influx of light to the soil surface, alkalization, and the input of salts with deicing mixtures) cause certain changes in the composition of algal flora. Shade-tolerant and salinization-sensitive species disappeared from the community, whereas photophilous diatoms with a prevalence of salt-resistant species preferring neutral soil reaction became dominants. There were also *Eustigmatophyceae*—unicellular algae belonging to forms that are particularly resistant to extreme conditions. As a result of these, the biodiversity of algae and cyanobacterial communities in the soils of the park increased in comparison with that in the native forest soils.

The microbiota is concentrated in the surface horizons of soils, and there is a decrease in the total number of bacteria and microbial biomass from the upper horizon to the lower horizons. However, when studying soil microbial communities at depths of 15, 30 and 90 cm in the Tiergarten Park (Berlin, Germany) [46], functionally active bacteria were found at a depth of 90 cm. Bacterial communities at a depth of 90 cm differed sharply from the communities in the two upper horizons. The ability of microorganisms to utilize various substrates decreased with depth.

The diversity of bacterial communities in urban parks depends not on the age of the park but on the soil characteristics (carbon and nitrogen contents, pH, and bulk density), which was shown by DNA extraction and sequencing of 16S rRNA from the surface horizons (0–10 cm) of the soils of 11 parks in Beijing [120]. The predominant groups of microorganisms isolated in this study were Proteobacteria, Actinobacteria, Bacteroidetes, Actinobacteria, Gemmatimonadetes, Verrumicrobia, and Planctomycetes. The effect of pH on the composition of microbial communities was also observed in New York parks: Acidobacteriales and Ellin6513 (Acidobacteria A052) were absent in alkaline soils on construction debris [77]. In addition, in conditions of low anthropogenic burden, the correspondence of fungal and bacterial communities to functional groups of plants was observed. At the same time, fungi are under more "strict control" of plants than bacteria, as demonstrated by the results of studying microbial communities in the soils of 41 parks in Lahti and Helsinki (southern Finland), of different ages and under different vegetation [75]. There was a positive correlation between the pH value of the soil and the richness of bacterial communities and a negative correlation with the value of their evenness. The pH value did not affect the diversity of fungi. When comparing parks created 10, 50, and more than 100 years ago, it turned out that soil properties and characteristics of bacterial and fungal communities are similar in parks of 50 years in age and in old parks, but differ from those in young parks. This suggests that the soils of the parks become stabilized in about 50 years after the creation of the park, and vegetation takes time to modify the properties of soils and communities of microorganisms. The maintenance of various types of green spaces in the city and various plant communities within them helps to ensure the full functioning of soils in an urban environment [75].

It is interesting to trace not only the composition of microbial communities but also their functional activity in the soils of urban parks. Bacterial and fungal communities of surface (0–10 cm) soil horizons and their functional genes were studied in 24 urban parks in Shanghai—one of the largest cities in China [118, 124]. Among 43 classified phyla, the highest relative prevalence was noted for Proteobacteria and Acidobacteria. A high diversity of genes involved in biogeochemical cycles of C, N, P, and S was revealed. However, some functional genes associated with the degradation processes of persistent organic compounds (enzymes cellobiase, glyoxal oxidase, lignin peroxidase) were absent in the soils of urban parks. The composition of fungal communities in all 24 parks was similar: five phyla were identified, among which Ascomycota prevailed in most of the park soils. The presence of representatives of ectomycorrhizal fungi in the parks emphasizes the role of park soils in biogeochemical cycles. According to the results of studying the surface (0–20 cm) soil horizons of urban and suburban parks, as well as roadside green strips of Beijing (China), a wide prevalence of arbuscular mycorrhiza fungi has been shown, which can be explained by the high content of organic matter and the introduction of mycelium and spores of non-indigenous fungal species together with the soil and planting material of introduced plants [86].

It is should be noted that among the soil micromycetes there are also potential pathogens for humans. In the surface horizons of the soils of parks and squares of Vladivostok (Russia), 86 species of microscopic fungi belonging to two groups—Zygomycota and Ascomycota—were identified by the method of serial dilutions followed by inoculation of soil suspension on Czapek's medium and wort agar. Also, 37 species (43% of the identified species) were potentially pathogenic, capable of causing mycoses and mycogenic allergies, which is typical for the urban environment [10].

CONCLUSIONS. RESULTS AND PROSPECTS OF SOIL RESEARCH IN PARKS

The analysis of the conducted studies indicates that the soils of urban parks are diverse in their morphology and genesis, because natural and anthropogenic soil forming process are superposed in the parks contributing to the spatial heterogeneity at the levels of individual soil profiles and soil cover. A phenomenon that unites the diverse soils of parks is their main function in urban ecosystems—the maintenance of longevity and decorative appearance of plantings, the species composition and appearance of which should correspond to the landscape and architectural design. However, the study of the genesis and evolution of the soils of urban parks is necessary, as it provides essential information about the stages of the historical park formation necessary for the development of measures for the maintenance and restoration of the existing parks and for predicting the sustainability of newly created parks.

As a rule, anthropogenic soils of parks are characterized by a neutral or alkaline reaction and an increased content of organic matter and plant nutrients, especially phosphorus.

As well as other urban soils, the soils of parks are subjected to technogenic pollution with HMs (Pb, Cu, Zn, Cd, etc.) and PAHs. Studies show that the accumulation of HMs in soils is more manifested in parks with a long history located in old cities with developed heavy industry and high traffic burden. The content and spatial distribution of HMs in parks reflect not only the current but also the previous stages of land use. Most publications attest to a negative impact of HMs on the microbial biomass and enzymatic activity of park soils. Among the enzymes, dehydrogenase is the most sensitive to inhibition by HMs.

During the study of park soils, most authors prefer to assess their pollution according to sanitary and hygienic criteria, focusing on the risks to public health. Without denying the importance of such studies, it is also important to develop and applying methods for assessing the ecological state of soils in terms of maintaining the sustainability of green spaces. This assessment should be universal, applicable to various urban landscaping facilities in different climatic conditions and take into account the totality of physical, chemical, and biological properties. Such universal indicators include the soil texture, the thickness of the humus layer, the bulk density of the topsoil (0–20 cm), the soil water content (in percent of the total water capacity), the temperature of the layer 0–20 cm, the electrical conductivity of the pore solution, pH, and respiration under standardized conditions [34, 111, 114].

The soil cover of parks is unique in that within the urban environment, natural or poorly modified soils can be preserved in its composition. Thus, the parks preserve not only the biological diversity but also the soil diversity of urban ecosystems. The soil fauna in urban parks of the world remains insufficiently studied; available data indicate its reduced species diversity in anthropogenic soils compared to the soils of natural ecosystems. To maintain mesofauna communities in the soils of parks, the presence of a litter layer and the characteristics of humus horizons play an important role. Unlike fauna, the diversity of microflora in anthropogenic soils is often higher than in natural communities, since various disturbances increase the number of potential ecological niches for microorganisms. In general, it can be noted that there is a need for a combined study of soils, plants, soil biota, and their functional relationships in parks, which would answer a number of important questions: how long does it take to achieve a balance between soils and plant communities in newly created parks? How do microorganisms in soils affect the sustainability of tree plantations under urban loads? What role does soil fauna play in these processes? The vital state of plants and their species diversity together with the number and diversity of soil organisms (bacteria, fungi, invertebrates) can serve as indicators of the optimal ecosystem functioning of park soils.

Another pressing question is: how to ensure the full functioning of anthropogenically constructed soils (soil-like bodies) in the ecosystems of parks? With such a design, it is recommended to create a fertile surface horizon of sufficient thickness, control the composition of the waste used, especially organic, and select a structure with optimal water-physical properties [122]. The control of the amount and quality of organic matter in soils used for the creation of a fertile layer and soil reclamation works in urban parks is also important from the point of view of maintaining the carbon balance in urban ecosystems [4]. It is recommended to treat the functioning soils preserved in the city as carefully as possible, since the colonization of newly created (constructed) soils (constructozems) with soil biota up to the natural level and the stabilization of their properties take decades.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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