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GENESIS AND GEOGRAPHY OF SOILS

Litters of Urban Stands as an Indicator of the Intensity of Biological Cycling in a Megapolis (by the Example of Bitsevsky Park, Moscow)

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Abstract—The intensity of biological cycling in urban park stands is assessed based on the following characteristics of the structure and functioning of forest litters: total litter stock, the stock and share of detritus in the L horizon, stock and share of easily degradable components (EDCs) in the L horizon, ratio of the stock in the L horizon to the total stock in underlying horizons, ash content in L horizon, and EDC ash stock and its share in the total ash stock in the L horizon. The study has been conducted in the Bitsevsky Park under spruce, birch, and linden stands. The examined urban stands considerably differ from the natural ones in the composition of the living ground cover, which contains meadow and weed–ruderal species, suggesting an anthropogenic impact. The urban stands differ from the natural ecosystems by an increased intensity of biological cycling, which is indicated by total stocks and shares of detritus, EDCs, and ash of EDCs in the L horizon. Under urban conditions, the litter of coniferous stands is simple in its structure, thin (no thicker than 4–5 cm), and contains more ash in its individual components (over 10%), which reflects a considerable contribution of the mechanical migration of solid particles of different origins. In the majority of characteristics, the litter of deciduous urban stands is less different from the analogous natural litter as compared with the litter of coniferous urban stands. Correspondingly, the litter under spruce stands may act as an indicator of anthropogenic impact on urban ecosystems. In general, the characteristics of biological cycling associated with the specific forest litter features suggest an increased intensity of biogenic migration as compared with the analogous natural phytocenoses. This should be taken into account when predicting the development of green urban landscapes.

Keywords: litters, biological cycling, urban stands, Albic Retisols

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INTRODUCTION

Biological cycling plays a key role in our understanding of the soil genesis, as is emphasized in the classical works by Vasily Williams and in generally recognized concept and methodology formulated by Bazilevich et al. [21], as well as in the recent papers by Titlyanova [1, 33]. According to Vernadsky, biological cycling is one of the most important characteristics of the sustainability of biosphere and is currently regarded as the most important criterion of its sustainable development [24]. This refers not only to the natural phytocenoses, but also to artificial ones, the role of which in the provision of optimal living conditions in modern megalopolises is ever increasing. The processes in urban forest stands require a special attention, including the search for indicators that reflect the patterns of their functioning.

The urban tree stands are of a paramount ecological importance [50] since they fulfill a wide range of ecological functions, including the litter acting as the geochemical barrier that retains pollutants [35]. The recreation function of urban stands in modern megalopolises can hardly be overestimated. Note that the functioning of phytocenoses in megalopolises differs from that under natural conditions in many respects, which is described in numerous publications on urban phytocenoses and soils. An increased content of heavy metals in urban soils [38, 43, 55, 57] requires the human health risks assessment [51]. Recent studies have clarified the specific features in the microbial pool [39] of the soils under urban stands, transformation of organic matter, and its migration, specifically [54]. As is emphasized, it is necessary to take into account the content of organic matter under impervious surfaces [37] and the influx of aerosols and dust [41]. Pollution of urban biogeocenoses with anthropogenic waste is considered [52]. The role of mesofauna in litter decomposition, especially with the input of technogenic and/or anthropogenic nitrogen to urban ecosystems, is emphasized [48] and an active involvement of macrofauna is noted as well as the significance of plant species diversity in the forest ecosystems functioning under urban conditions [47]. Of interest are the studies on how fine root systems contribute to the intensity of litter decomposition [56]. The dynamics of changes in the C : N : P ratio in plant leaves and roots has been shown in terms of stoichiometry [42]. The case study of 27 parks in Finland demonstrates that the intensity of carbon accumulation under evergreen plants is higher versus the deciduous species [49] although it is lower as compared with natural forest communities. Close values of the carbon content in park soils suggest that the removal of fallen leaves has an insignificant effect on the carbon accumulation in the soil.

These data convincingly demonstrate the ever-increasing interest to the research into the components of urban ecosystems and their functions, as well as the specific features of biological cycling in urbanized areas. The domestic scientific literature uses several parameters that characterize the state of the litter. One of the basic parameters is the ratio of litter to leaf waste stocks, which characterizes the cycling intensity [21]. The state of the litter is used in evaluation and grouping of forest lands and quality assessment of forest soils [34]. Classification of litters relies on their morphogenesis [3, 24], and their typology correlates well with the criteria reflecting the rate of matter turnover in biogeocenoses, as has been convincingly demonstrated for the stands of the Botanical Garden in the Lomonosov Moscow State University. Calculation of ratios of the litter stocks assessed in summer and fall seasons [29] gave the estimate of the organic matter utilization in litter in the annual cycle. Conceptually, the methodological basis for the study of litters in natural and urban stands is the same, namely, starting with typological specification to structural organization. The functional patterns of urban and natural phytocenoses are similar and primarily depend on the species composition; correspondingly, the search for specific features in the transformation of ground detritus is relevant from both scientific and practical standpoints. We cannot but admit that any precise indicators and characteristics able to distinguish between natural and urban phytocenosis in terms of biological cycling are absent because the phytocenoses in urban landscapes are poorly studied. Correspondingly, the research into biological cycling in megalopolises is a relevant challenge.

The goal of this work was to assess the intensity of biological cycling in urbanized areas based on the estimated parameters of the litter structural organization in urban park stands.

OBJECTS AND METHODS

The Bitsevsky Park is a nature reserve with an area of 2208 ha, founded in the City of Moscow in 1994. The climate here is humid and moderately continental with distinct seasonal patterns. The mean annual temperature is +5.4°C; mean annual precipitation, 650 mm; and annual evaporation capacity, 434 mm. The Bitsevsky Park is situated in the southeast of the Teplostanskaya Upland, which is a distinct natural region formed on a preglacial residual mound on the Oksko-Moskvoretskaya Plain [8]. The relief is hilly with a dense network of ravines represented by deep erosion valleys of different sizes [25]. The prevalent soil-forming rock on the interfluves are carbonate-free medium and heavy loams, Moscow and Dnepr moraines, and glaciofluvial deposits on them. The area of the Bitsevsky Park belongs to the subzone of coniferous and broadleaved forests. The forest ecosystems (spruce, oak, linden, and birch stands) occupy up to 63% of the park area [36]. The average age of the forest stands there is 84 years. The soil cover is nonuniform with the prevalence of soddy-podzolic mainly medium loamy soils differing in podsolization rate [14].

The studied objects are represented by three typical plantations occupying approximately 400 m^2 each. The spruce and linden stands are at a distance of 70 m from the nearest roadway (Golubinskaya street) and 15 m from one another. This location does not exclude the possibility of leaf waste exchange. The birch stand is at a distance of 2.5 km from the two other objects and of 315 m from the road (Akademika Kapitsy street). The stands are situated on well drained sites of gentle slopes.

The cow wheat–gramineous birch stand is 70 years old. The stand is formed of the silver birch (*Betula pendula*). The orchard grass (*Dactylis glomerata*), cow wheat (*Melampyrum nemorosum*), and redtop (*Agrostis gigantea*) are prevalent in the dense grass cover (projective cover reaches 90%); the soil was qualified for soddy-podzolic [13] (Albic Retisol).

The buttercup–bugle linden stand is 70 years old. The tree layer is formed of the small-leaved linden (*Tilia cordata*). The bulge (*Ajuga reptans*) and buttercup (*Ranunculus cassubicus*) are prevalent in the grass stand; the soil was qualified for soddy-podzolic (Albic Retisol).

The common nettle–bulge spruce stand is 100 years old. The European spruce (*Picea abies*) with the small-leaved linden (7 spruces : 3 linden trees) is prevalent in the tree canopy. The bulge (*Aiuga reptans*) and common nettle (*Urtica dioica*) are prevalent in the grass stand; soddy-podzolic soil (Albic Retisol).

The understorey (shrub layer) is almost absent and the regrowth is poor, i.e., the stand structure is simple, which is typical of urban stands.

All field studies of the selected phytocenoses were conducted in test plots of 10 × 10 m. Vegetation was described in terms of botany. The species of the grass layer, with a special focus on it as the layer most sensitive to local ecological conditions, was regarded as belonging to ecological–cenotic accompanying plants or groups of plants according to Nitsenko [19]. The litters in deciduous stands were sampled from plots of 50 × 50 cm in nine replicates. As for coniferous stands, the litter was sampled in five replicates taking into account their position in the tessera, a single tree's

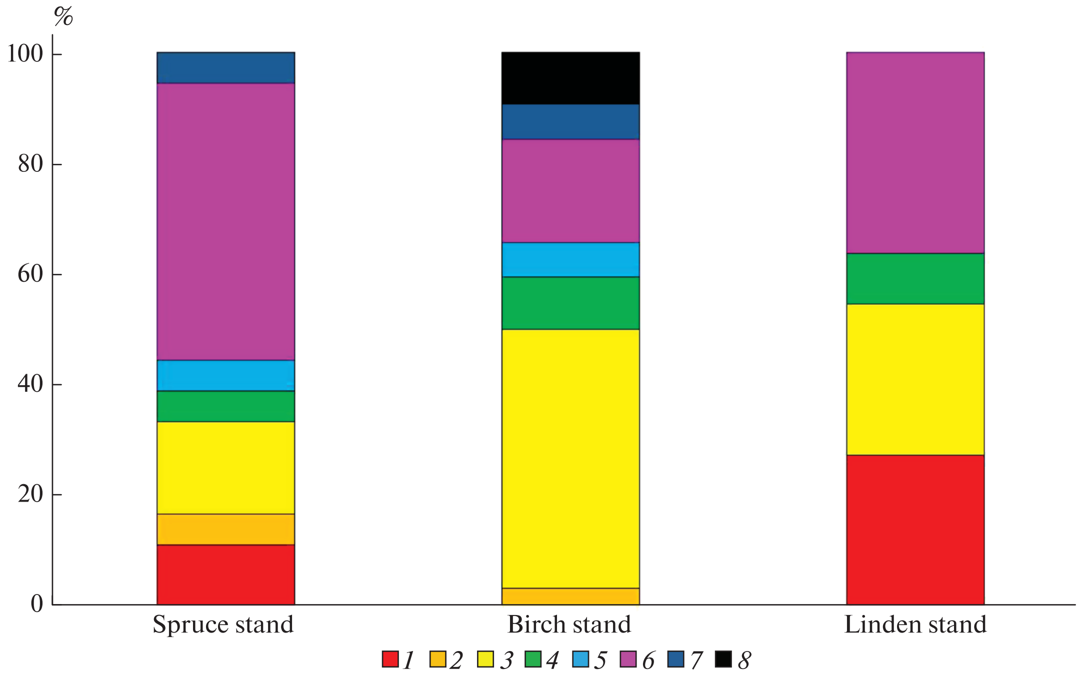

Fig. 1. Ratio of the species belonging to different ecological–cenotic groups in the grass layer: *1,* weed–ruderal accompanying species; *2,* meadow nitrophilic accompanying species; *3,* other meadow accompanying species; *4,* small-leaved edge–opening accompanying species; *5,* aspen accompanying species; *6,* nemoral accompanying species; *7,* spruce accompanying species; and eurytopic species.

soil, namely, near-trunk–crown–clearing. The litters were classified using the system by Bogatyrev [3].

The litters were sampled in a layerwise manner. The upper L horizon was divided into the following fractions: leaves, needles, branches, bark, cones, and dead parts (grass waste). The small components of horizon L of the unclear origin were regarded as detritus. The dead residues and leaf fractions together were referred to as easily degradable components (EDCs); their content and stock are very important characteristics because these particular components are the first to be decomposed by microorganisms and are actively transformed by soil invertebrates [40]. The stocks of all fractions and of litter were calculated per absolutely dry weight. The ash content for the litter components was determined by ignition at 450°C. The resulting data were used to compute the following parameters characterizing the function of litters: (1) total litter stock; (2) type of the structure (destructive, fermentative, or humified); (3) the ratio of the stock in the L horizon to the total stock in the remaining horizons (if applicable); (4) stock and share of EDCs in L horizon; (5) stock and share of detritus in L horizon; (6) weighted average ash content in L horizon; and (7) stock of EDC ash and its share in the total ash stock in the L horizon.

The characteristics of biological cycling for the analogous natural spruce, linden, and birch stands in the territory of the Chashnikovo Educational–Experimental Soil and Ecological Center with Lomonosov Moscow State University were calculated based on the earlier published data [32, 53] to clarify the specific cycling features for urban conditions.

The data were statistically processed using Excel and Statistica software.

RESULTS AND DISCUSSION

Specific features of the living ground cover. An urban forest represented by the studied fragment of the Bitsevsky Park is an intermediate formation between a forest and a park [18], which is reflected in the living ground cover. The studied phytocenoses correspond to the digression stages III (birch stand) and III–IV (linden and spruce stands). This is suggested by the presence of meadow and weed–ruderal species in the grass cover and their ratio to terminal species [23]. However, note that the phytocenoses considerably differ in the composition of their living ground cover (Fig. 3).

The highest number of species (23) was observed in the birch stand and the lowest, in the linden stand. In addition to the potential recreational impact, the species diversity of the living ground cover in the spruce and linden stands is determined by the degree of illumination, which is lower in these stands as compared with the analogous natural stands because the light

Table 1. Distribution of different litter types within tesseras, number

Litter type	Tesseras		
	Trunks	Crowns	Open areas
Destructive	1	3	4
Fermentative	4	2	1

regime commences to considerably change starting from the digression stage III [6].

Many nemoral species, accompanying broadleaved trees, were observed in all examined stands, which is a typical pattern for the parks of Moscow [11, 20]. The grass layer of birch stands has a large share of meadow (redtop *A. gigantea,* 47%) and nemoral (cow wheat *M. nemorosum,* 19%) species. Forest edge species (spotted St. John's Wort *Hypericum maculatum*) and eurytopic (meadow buttercup *R. acris*) species are also important. This combination of accompanying species is characteristic of the small-leaved stands planted in the subzone of coniferous–broadleaved forests. Weed species were undetectable; this is explainable by a considerable distance of the site from the walking routes and roadways as well as by the competition with meadow species, especially gramineous ones.

Characteristic of the examined linden stand is a low diversity of the living ground cover and the minimum number of ecological–cenotic accompanying species. The prevalent species (accounting for 36%) forming this ground cover are the nemoral plants: buttercup *R. cassubicus* and bulge (*A. reptans*). The other plants belong to meadow (moneywort *Lysimachia nummularia*) and weed–ruderal (common nettle *U. dioica* and small-flowered touch-me-not *Impatiens parviflora*) groups. Note that the moneywort, which has the largest cover rate, is tolerant to trampling [5]. A large share of synanthropic plants results from a small distance to large park walking routes and roads (70 m).

Nemoral species (bulge and wood avens *Geum urbanum*) are the most abundant, accounting for 50% of the grass cover; a certain prevalence (17%) of meadow species are observed, including moneywort, creeping buttercup (*R. repens*), and horse sorrel (*Rumex confertus*). The presence of sun-loving plants is most likely associated with the absence of regrowth and few undergrowth plants, which do not give much shadowing, which characteristic of natural coniferous stands. The spruce-accompanying species are also met, such as the European goldenrod (*Solidago virgaurea*).

An increased share of nemoral species in the living ground cover may be determined by the specific features of urban microclimate, which differs from that of natural phytocenoses. The weed–ruderal species may appear owing to both direct recreation and the seed transfer from urban landscapes of residential area. The simple vertical structure of park phytocenoses also creates an additional open space [28], thereby assisting the distribution of the species with an increased ash content, untypical of natural forests. The latter fact characterizes the specific features of biological cycling.

Because of the simplified vertical structure of phytocenosis, the biomass of regrowth and bushes is either reduced or absent, which decreases the stock of organic matter and ash elements in the ecosystem, that is, the capacity of biological cycling.

Properties of Forest Litters

Coniferous stands. The litter observed in the Bitsevsky forest is of two types—destructive and fermentative (Table 1). Note that the fermentative litter type is prevalent in the under-trunk area; destructive type is more characteristic of inter-crown clearings; and both types are present under the crowns in approximately equal shares. Fermentative horizons are intermediate between L and F horizons in the recreational stands, where the humified and fermentative litter horizons are rather thin. The last fact is associated with both a high rate of organic matter decomposition and mechanical litter destruction by trampling [2, 7, 15].

These specific morphological features are untypical of the natural spruce stands, where not only fermentative, but also humified litter types are observable, especially in the near-trunk areas [53]. The litter layers are thin and become thinner within the tessera from near-trunk to inter-crown open areas down to 1 cm (Fig. 2), which is untypical of the spruce phytocenoses. The thickness of the forest litter in the inter-crown clearings is the only parameter that significantly differs from other components of the tessera. The LF2 horizons, transitional to the humified ones, are very thin (less than 1 cm) and are developed only in the under-crown and near-trunk areas. The litter stocks change in a similar manner, being almost tenfold higher in the near-trunk area as compared with the inter-crown clearings. As for the natural spruce stands, these differences within a tessera are 15–20-fold [4, 53]. Presumably, urban conditions somewhat level the variation in the litter thickness and stocks within a phytocenosis. A decrease in the stock and thickness of litter as compared with the natural forests is, in particular, associated with the recreational impact [45].

Branches and needles are prevalent in the L horizon of all litters in the spruce stands (Fig. 3). An increased amount of branch waste may suggest the adverse growth conditions resulting from an increased anthropogenic impact [45] since coniferous stands are less tolerant to atmospheric pollution as compared with the deciduous forests [12]. Detritus accounts for a relatively small share (up to 5–6%) as compared with the litter of natural spruce stands [31]. Presumably, this is associated with more favorable conditions for organic matter decomposition as compared with natural phytocenoses or with mincing of detritus owing to

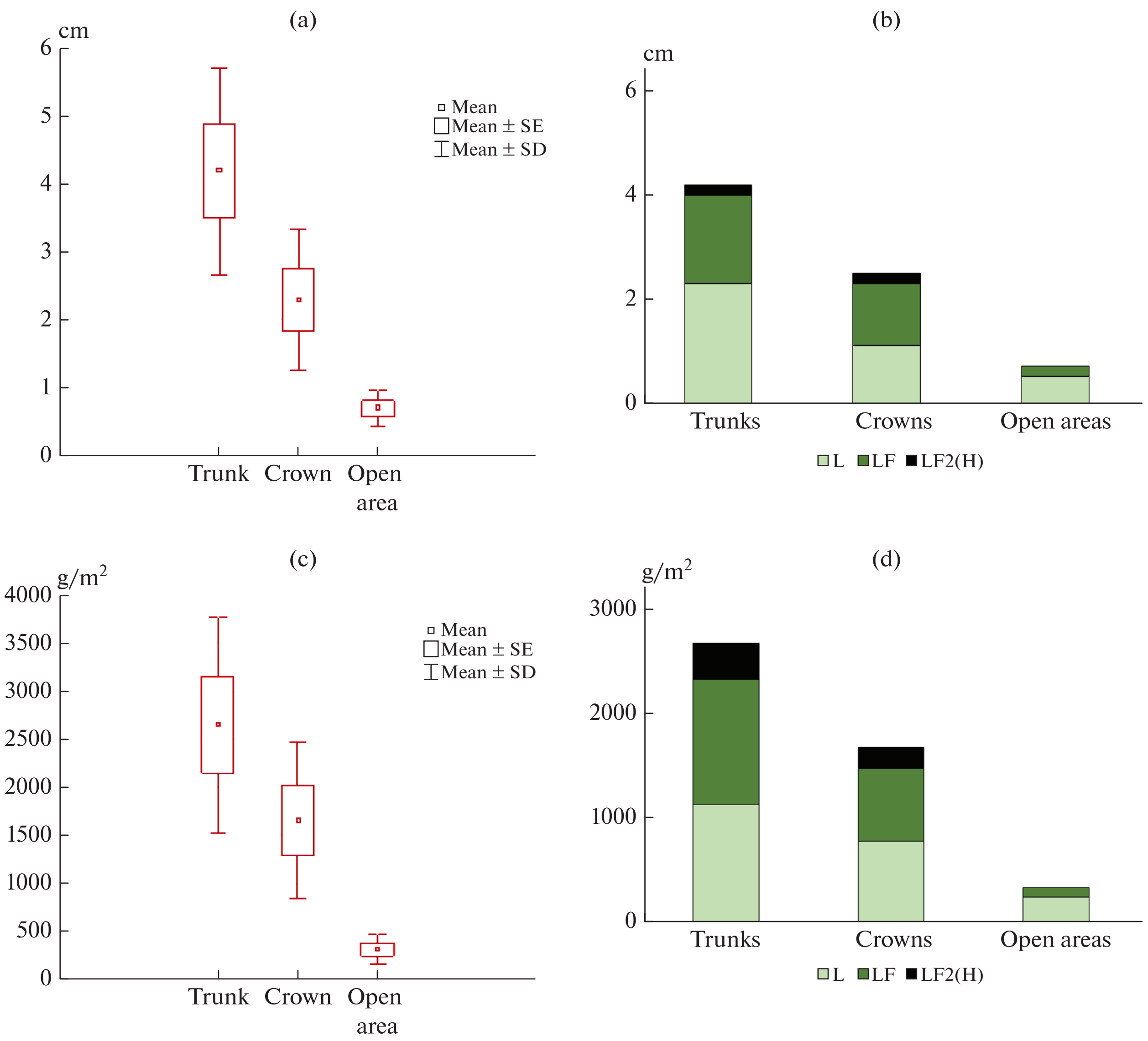

Fig. 2. (a and b) Thickness and (c and d) stock of coniferous stands: (a and c) total and (b and d) according to horizons.

the recreational impact, which accelerates its mineralization. A minimum content of detritus is observed in the L horizon of forest litter in the inter-crown clearings within a tessera. The fraction of dead parts (<2 g/m^2) is almost absent, most likely because of a small projective cover of the grass layer. The stock and share of leaves in the L horizon increase from trunks to the open area. The stock of litter EDCs almost does not change from the trunks to clearings, whereas their share increases four–fivefold in this direction. The natural spruce stands of the taiga zone and coniferous–deciduous subzone display an analogous pattern [31, 53]. Presumably, this is associated with the changes in the leaf waste composition and the conditions of its decomposition from the near-trunk elements of tessera towards the clearings.

The weighted average ash content in the litter L horizons is 8–12%; its components with the highest ash content are dead parts of plants (26–27%) and detritus (16–22%), which agrees with the earlier data on the ash content in the litter of urban landscapes [27]. Presumably, this is the result of considerable plant pollution by dust, which enters the litter with plant waste [10]. Recreation allows for an additional input of mineral particles, which is a possible explanation for a relatively large litter stock on the background of its thinness. The ash content in the lower litter horizons, considerably intermixed with mineral horizons, reaches 30% (Table 2). The total stock of ash elements accumulated in litter layers and individual horizons decreases fourfold from the near-trunk to the inter-crown areas; this is determined by a similar pattern in

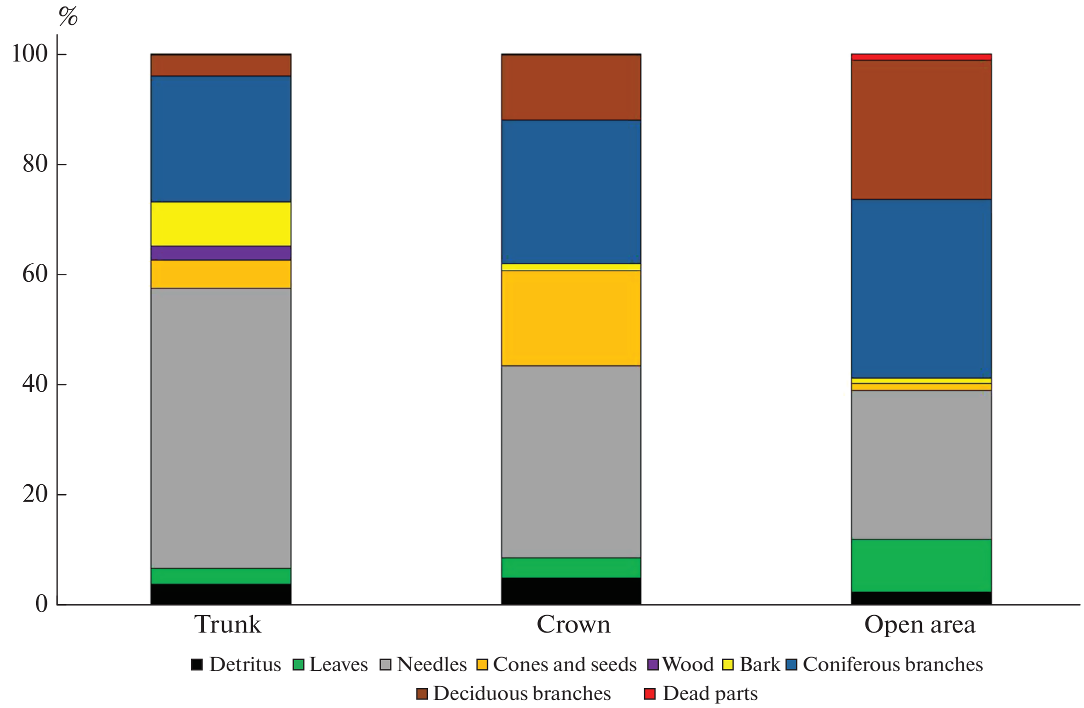

Fig. 3. Shares of different horizon L fractions in the litter of spruce stands, %.

the spatial distribution of litter stocks. Note that the share of ash elements in L horizon as compared with the total ash in the litter amounts to 20–30% in the near-trunk and under-crown areas and exceeds 50% in the inter-crown clearings. The largest share of ash elements in the L horizons is accumulated at the expense of needles and branches.

Thus, the litter of urban spruce stands under conditions of active recreation has a simple structure, is thin on the background of increased stock and ash content, and displays a distinct spatial differentiation within tesseras. As a rule, the fermentative litter types are confined to the near-trunk microhighs with their larger stock of mortmass as compared with other parts of tesseraes

Deciduous planted stands. The litter types in both kinds of stands were identified as primitive destructive, i.e., composed of only one horizon (Table 3). They are very thin, not exceeding 1 cm, which is thinner as compared with the litter of the stands of the same types in the Botanical garden of the Lomonosov Moscow State University [30]. For the Bitsevsky Park, this is explainable with the recreational impact. However, note that the litter stock (Fig. 4) matches in general the data on other planted linden and birch stands in parks [32]. The litter stock in the linden stand is considerably larger as compared with the birch stand, which is associated not only with that the linden is a broadleaved tree unlike birch, but also with several other factors. The clearings are larger there in comparison with natural phytocenoses of the Botanical garden of the Lomonosov Moscow State University; correspondingly, the lateral transfer of plant waste and litter components is more intensive; in addition, the transfer of birch leaves is more active because of their smaller size. Correspondingly, the litter in urban stands is formed of the waste of both edifier trees and the wind-driven waste. Branches and leaves are prevalent in the litter fractional compositions of both deciduous stands (Fig. 5); note that the amount of leaves is

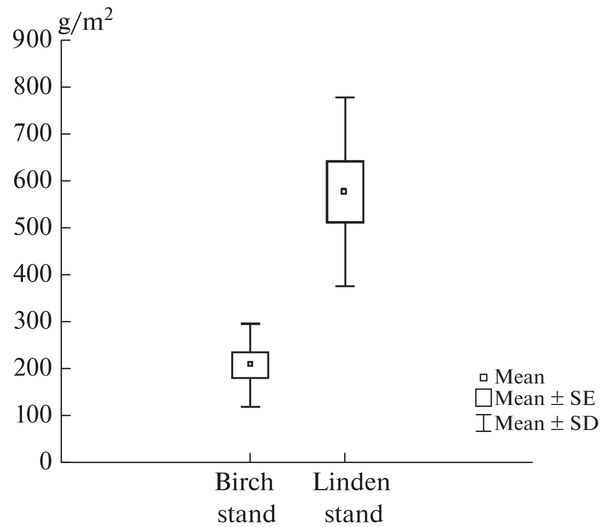

Fig. 4. Stock of the litter in deciduous stands, g/m^2.

Table 2. Properties of litter components in coniferous stands, mean ± standard error

Horizon or its component	Trunks	Crowns	Open areas
	Ash content, %		
Leaves	15.7 ± 1.4	13.6 ± 1.5	16.1 ± 0.6
Dead parts	26.4 ± 0.7	–	27.0 ± 3.6
Needles	11.96 ± 0.1	12.9 ± 1.3	17.58 ± 1.3
Detritus	17.5 ± 2.8	16.0 ± 1.8	22.0 ± 4.0
Coniferous branches	6.13 ± 0.6	5.81 ± 0.5	7.5 ± 0.1
Deciduous branches	5.5 ± 0.5	5.3 ± 0.5	8.7 ± 0.6
Bark	7.7 ± 1.1	7.9 ± 0.4	7.0 ± 1.7
Wood	5.5 ± 1.4	–	–
Cones	4.9 ± 0.5	3.5 ± 0.8	–
Seeds	13.7 ± 1.6	–	21.7 ± 4.0
L (weighted average)	9.86 ± 0.6	8.4 ± 0.5	12.24 ± 1.5
F	25.6 ± 4.4	17.1 ± 3.3	25.5
H	39.1	31.1	–
	Ash stock, g/m^2		
Leaves	4.2 ± 2.0	4.14	3.63
Dead parts	0.43 ± 0.3	–	1.09
Needles	71.3 ± 16	30.17	10.84
Detritus	6.6 ± 2.0	5.97	2.41
Coniferous branches	15.4 ± 1.3	10.89	5.33
Deciduous branches	2.8 ± 2.8	5.94	7.85
Bark	8.2 ± 1.4	1.34	0.45
Wood	1.4 ± 0.7	–	–
Cones	2.6 ± 0.6	3.24	–
Seeds	0.8 ± 0.2	1.9	0.75
L (total)	114.1 ± 18	61.4 ± 11	27.5 ± 5.5
LF	162.1 ± 32	121.0 ± 41	23.6 ± 23.6*
LF_2(H)	134.6 ± 134.6*	61.0 ± 61*	–
Sum for litter (mean)	**410.8**	**243.4**	**51.1**

* The horizon is developed only in one tessera of the five examined.

Table 3. Morphological structure of the litter in deciduous stands

Phytocenosis	Horizon	Thickness, cm	Classification state
Cow wheat–gramineous birch stand	L	0.7 ± 0.1	Destructive, moderately conjugated, primitive, very thin, deciduous
Buttercup–bugle linden stand	L	0.8 ± 0.2	

always larger in the birch litter. Dead parts of plants are almost absent in the linden litter since the grass layer is poorly developed because of shadowing. On the contrary, the litter of birch stand contains up to 10% of dead parts. The litter of linden stand contains needles and cones because of the lateral wind-driven transfer; this situation is frequently observable in park stands [4, 29, 30]. The share of detritus is small, especially in the birch stand, and is absent in some litters.

Leaves have the highest ash content among the litter components (12.6 and 14.9% for the birch and linden stands, respectively) as well as the dead parts (16.5 and 27.0%, respectively). In general, the ash content of the L horizon amounts to 9.4% for birch and 11.4% for linden stands, which is close to the L horizon of spruce stand (Table 4). Commonly, the ash stock in the litter, as well as in the leaf and detritus fractions is larger in the linden stand as compared with the birch one at the expense of both total litter stock and the ash content. Note that the sum of ash elements accumulated in the birch litter L horizon is considerably smaller as compared with the spruce stand. The sum of ash elements in the linden stand exceeds that in the spruce stand L horizon except for the near-trunk microhighs.

Characteristics of litter function. The parameters of litter that indicate the intensity of biological cycling were assessed (Table 5), beginning with the typology of litters to the detritus, EDCs and their stocks.

The characteristics of litter, such as the ratio of horizons, stocks, and contents of detritus and EDCs,

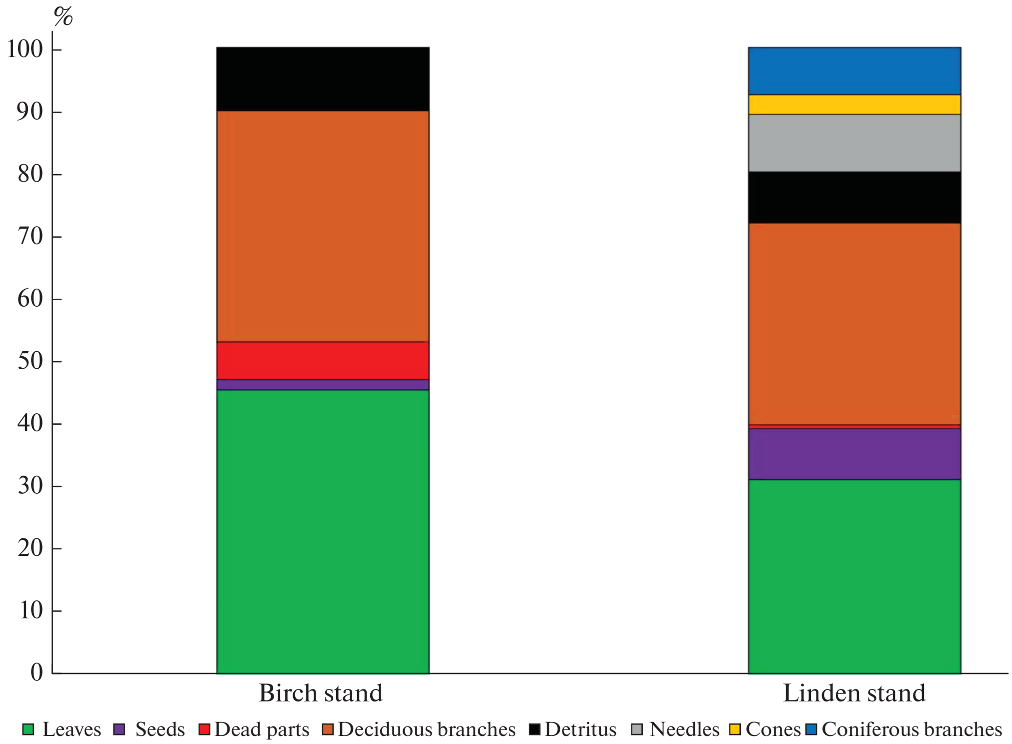

Fig. 5. Fractional composition of the litter in deciduous stands, %.

Table 4. Properties of litter components in deciduous stands, mean ± standard error

Horizon or its component	Deciduous stands	
	Birch stand, 70 years old	Linden stand, 70 years old
	Ash content, %	
Leaves	12.6 ± 0.8	14.9 ± 1.6
Dead parts	16.5 ± 1.0	27.0*
Needles	–	21.2 ± 1,6
Detritus	14.4*	20.1*
Coniferous branches	–	8.3 ± 0.3
Deciduous branches	4.1 ± 0.5	7.6 ± 0.5
Bark	–	14.5*
Cones	–	6.4 ± 0.8
Seeds	5.9*	9.2 ± 0.6
L (weighted average)	9.4 ± 0.8	11.4 ± 1.7
	Ash stock, g/m^2	
Leaves	13.0 ± 2.6	32.8 ± 12.2
Dead parts	2.2 ± 0.6	0.33 ± 0.1
Needles	–	10.5 ± 3.6
Detritus	2.5 ± 1.8	7.9 ± 4.8
Coniferous branches	–	2.9 ± 1.1
Deciduous branches	3.6 ± 0.7	14.2 ± 1.8
Bark	–	0.6 ± 0.2
Cones	–	0.8 ± 0.6
Seeds	0.1 ± 0.04	3.3 ± 1.9
L (total)	23.2 ± 2.3	73.87 ± 14.6

* Fraction is observed only in one sample of the nine examined.

Table 5. Characteristics reflecting specific features in the functioning of forest litters studied

Characteristic	Spruce stands						Birch stands		Linden stands	
	Urban			Natural			Urban	Natural	Urban	Natural
	Trunk	Crown	Open area	Trunk	Crown	Open area				
Litter stock, g/m^2	2600	1600	350	4428	3526	2056	200	397	590	248.5
Ratio of litter types, D : F : H*	20 : 80 : 0	60 : 40 : 0	80 : 20 : 0	60 : 40 : 0	65 : 20 : 15	40 : 60 : 0	100 : 0 : 0	45 : 55 : 0	100 : 0 : 0	100 : 0 : 0
Detritus stock, g/m^2	43.9	36.9	5.0	70.6	163.2	93.3	8.1	20.6	39.4	0
Detritus, %	3.8	4.9	2.3	10.4	20.0	20.0	4.0	6.3	8.0	0
EDC**, g/m^2	34.6	27.8	23.4	77.2	148.9	179.6	114.0	169.1	194.0	38.1
EDCs, %	2.9	3.7	10.7	11.4	18.3	38.6	56.0	51.4	33.0	15.3
L/(F + H)***	0.79	0.50	0.60	0.18	0.30	0.30	–	4.8	–	–
EDC ash, g/m^2	4.6	4.1	4.7	4.9	15.6	16.4	15.2	29.8	45.0	19.8
Share of EDC ash in L, %	4.0	6.7	17.1	25.2	42.9	97.0	65.0	66.5	44.0	22.1
Ash content in L, %	9.8	8.4	12.2	7.3	10.8	10.7	9.4	14.5	11.4	7.3

* D, destructive; F, fermentative; and H, humified.
** EDCs, easily degradable components.
*** Ratio of the stock in L horizon to the total stock of the remaining horizons.

are associated with the intensity of cycling in ecosystems [4, 21, 29, 34], especially when they are considered together rather than individually. A low stock of litter and its simple structure are associated with a high rate of organic matter decomposition in litter as well as a low stock and share of detritus. An increase in the rate of litter decomposition mostly accelerates the cycling of organic matter and ash elements, thereby contributing to the intensity of biological cycling in the ecosystem.

In general, the characteristics of litter function in the urban territory suggest a comparatively high cycling intensity in urban parks. This is explainable with both the effect of urban microclimate on all processes, including the decomposition of organic matter, and the anthropogenic impact, unavoidably influencing the microbial activity in soil and forest litter [44, 46]. Mincing of the litter components during recreation also enhances an increase in the biological activity there [16, 17, 22]. The ash elements liberated in the course of decomposition of plant dead parts with an increased ash content, as well as brought with the dust on plant leaves are included into the cycling and influence the activity of microbiota and the rate of organic matter decomposition. The litter of deciduous stands significantly differs from the litter of coniferous stands in the stock and share of EDCs, ash stock in these components, share of EDC ash in the total ash content of litter, and weighted average of the ash content in the L horizon. These differences suggest a high intensity of cycling in the deciduous stands as compared with the coniferous ones, which is observable in the natural forest ecosystems. Note that the share of detritus in L horizon is almost the same in the examined planted stands. Presumably, this share is very small in all urban stands especially due to recreational impacts. Although the share of minced fractions increases during recreation [45], the formed detritus, especially in the litter of destructive type, is mixed with mineral horizons under the recreational impact and is thus absent in the litter *per se*, while the minced fractions are actively decomposed. The total stock of detritus is most likely determined by the total stock of litter because the shares of detritus in different stands are close.

The structure and stock of litter also suggests an intensive decomposition of organic matter in urban deciduous stands. Note that the litter stocks in the spruce biogeocenosis are more variable as compared with the variation between the biogeocenosis differing in their edifier tree species. The intensity of organic matter decomposition in the spruce stand increases, at least at the level of litter, from the near-trunk area to the inter-crown free space even under urban conditions, where the natural cycling processes are leveled by an anthropogenic impact. This is reflected in almost all studied structure–functional litter characteristics, namely, a decrease in the thickness and stock, transition of the litter from fermentative to destructive type, and an increase in the share of EDCs and ash content in the L horizon.

For comparison, see the analogous characteristics of litters earlier calculated for the linden, spruce, and birch planted stands in the territory of the Chashnikovo educational–Experimental Soil and Ecological Center with Lomonosov Moscow State University, where they are free from any recreational impact and

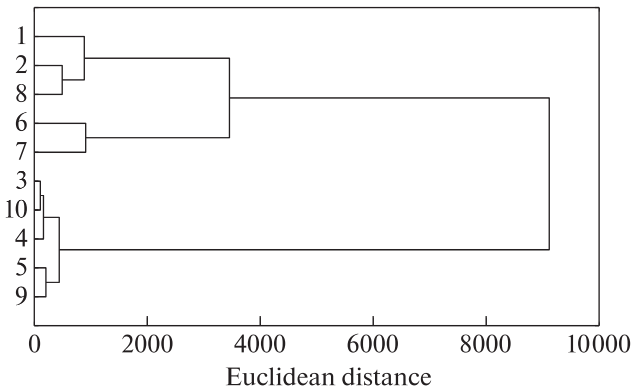

Fig. 6. Results of cluster analysis of the main litter characteristics in the examined stands: *1–3,* spruce stand in Bitsevsky Park, including *1,* trunk; *2,* crown; and *3,* intercrown open area; *4,* birch stand in Bitsevsky Forest; *5,* linden stand in Bitsevsky Park; *6–8,* spruce stand in Chashnikovo, including *6,* trunk; *7,* crown; and *8,* intercrown open area; *9,* birch stand in Chashnikovo; and *10,* linden stand in Chashnikovo.

considerable atmospheric pollution from highways [32, 53]. The stands there also grow on soddy-podzolic loamy soil. The birch and spruce stands are natural and the linden stands are planted but off-hand (the natural linden phytocenoses on soddy-podzolic soil are almost absent). The most pronounced differences in the function of forest litter in urban stands as compared with the litter in natural forest communities are observed in the spruce phytocenoses. Their litter stocks differ twofold in all components of tessera. Humified litter type is observed in the natural spruce stand and fermentative types are abundant. The content of detritus in the L horizon of urban forest communities is by one order of magnitude lower as compared with the natural stands. On the other hand, both the stock and share of EDCs are higher in natural stands, which is presumably associated with the developed undergrowth and ground cover as well as larger volume of plant waste.

A cluster analysis (Fig. 6) of the main characteristics of forest litter (total litter stock, the stock and share of detritus in the L horizon, stock and share of EDCs in the L horizon, ash stock in EDCs, share of ash in EDCs in the total ash stock in L horizon, ash content in L horizon, and shares of the fermentative and humified litter types among the examined litters in a phytocenosis or a component of tessera) distinguishes two groups, namely, the litters of coniferous and deciduous stands. The litters of urban and natural coniferous stands are pooled into one group and display certain differences between urban and natural phytocenoses. The exception there is the litter in the inter-crown clearings of urban stands, represented by a destructive type, similar to the litter under deciduous stands. As for the litter of planted deciduous stands, any considerable differences neither in their locations (urban or the localities near Moscow), nor in the edifier tree species are observed.

CONCLUSIONS

(1) The specific features of urban tree stands are simple vertical structure and presence of meadow and weed–ruderal species in the living ground cover, which is untypical of the natural phytocenoses with analogous species composition; they result of an integrated anthropogenic impact. The simplification of vertical structure of phytocenoses leads to an increase in the open spaces, which in turn enhances an increase in the interaction between biogeocenoses, appearing as an active exchange of plant waste between adjacent biogeocenoses;

(2) Two groups of litter abundant in the coniferous and deciduous stands are distinguished. Characteristic of the latter is the maximum turnover rate of organic matter and ash elements assessed based on the parameters reflecting the specificity of their function: total litter stock, the stock and share of detritus in the L horizon, stock and share of EDCs in the L horizon, ratio of the stock in L horizon to the total stock in the underlying horizons, ash content in horizon L, and stock of EDC ash and the share of the ash of these components in the total ash stock in the L horizon, which is also characteristic of natural territories;

(3) Characteristic of the litter of coniferous stands is an increased deposition of carbon and ash elements, which appears as its greater thickness, complicated structure, and larger stock. Under urban conditions, the main characteristics of the litter in coniferous ecosystems, unlike the deciduous ones, significantly change in a regular manner in response to urbanization, which makes it possible to use them as indicators of the state of ecosystems in a megalopolis;

(4) An increased ash content in the litter of both coniferous and deciduous stands reflects a considerable involvement of a mechanical migration of solid particles of different origins: mineral particles enter the litter both during recreation and with plant waste, which absorbs dust particles from the atmosphere;

(5) Characteristic of the urban park stands is a relatively increased intensity of biological cycling. The cycling capacity, partially decreased because of a simple structure of phytocenosis, associated with a reduction in the regrowth and undergrowth layers, is compensated by the integration of dust particles of an anthropogenic nature into the cycling. The latter can be involved into soil-forming processes; and

(6) Analysis of the parameters of biological cycling associated with forest litter has shown that the intensity of biological migration under urban conditions is higher as compared with natural ecosystems, which should be taken into account when predicting the development of landscaped areas and planning protection activities in the natural urban component.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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SPELL: OK