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ECOLOGY

Quantitative Assessment of the Effect of Recreation on Vegetation, Forest Litter, and Soil Compactness in Forest Parks of Moscow

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Abstract—The quantitative characteristics of vegetation, forest litter, and soil status at different stages of recreation digression are discussed by the example of the Losinyi Ostrov and the Bittsevskii Les forest parks (Moscow). Plant cover is most sensitive to recreation impact: successions of its parameters are already seen at transition to stage II of ecosystem digression. Forest litter type is changed at stages III and IV, and a statistically significant drop in its reserves occurs at stage V. The compactness of the top mineral soil layer increases statistically by 0.24–0.28 g/cm^3 at rather high recreation impact at stages IV and V.

Key words: recreation, level of recreation impact, stage of recreation digression, forest parks of Moscow

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INTRODUCTION

The problem of the stability of urban ecosystems has become especially urgent with the growth of city population, which comprises more than half of global population. Parks and forest parks play an important role in the sustainable functioning and preservation of urboecosystems. Forest parks are natural islands in urban areas. They are very a valuable resource for recreation because the environment they provide is favorable for relaxation and the promotion of health. At the same time, recreation is one of the main negative anthropogenic factors affecting urban and suburban forest ecosystems [2, 6, 15–19, 21, 22]. Forest parks where people may walk freely undergo the strongest negative influence [2, 15–19].

There are different approaches for the evaluation of recreation load. They are represented in the Industry Standard [13]. The use of a registration-measurement approach based on the quantification of the number and occupancy time of visitors is restricted by practical difficulties. In this connection, the recreation load is usually evaluated by the part of the studied area trampled down to the mineral horizon. Five levels of recreation impact are specified with respect to this parameter [13]. Each of them corresponds to a digression stage (DS) characterizing the phase of biogeocenosis succession. This approach is used in recreational forest science. Beginning with works by R.A. Karpinosova, five-stage digression (according to L.P. Rysin [16, 17]) has been widely used. There are works in which a greater [16, 17] or smaller [15, 19] number of stages of recreation successions are specified. At the present time, there is more than one opinion, concerning what recreation load on forest is considered critical [2, 6, 15–19]. According to data obtained by S.A. Dyrenkov and S.N. Savitskaya (according to [18]) forest parks of Leningrad investigated based on the concept of four-stage digression show that forest destruction after digression stage II may only be stopped by reconstruction. Based on data on broadleaved and pine forests near Moscow, G.A. Polyakova et al. (according to [18]) came to the conclusion that stage III of recreation digression is critical. The absence of a clear-cut solution to this problem is probably explained by the different stability of various soil types at a similar recreation load and by a lack of data to determine a quantitative correlation between forest biogeocenosis status and the level of recreation impact.

Recreation affects all forest components [2, 14–19, 21, 22]. Not only the qualitative, but also the quantitative dependence of forest components on recreation load should be studied for the determination of stability of recreation forests. The components most sensitive to anthropogenic impact are of prime interest. Numerous investigation data testify to the high sensitivity of vegetation and forest litter [2, 6, 15–19, 21, 22]. Among soil properties, the compactness of top mineral layer responds first to recreation load. Its greatest transformation is seen for forest litter destruction. Greater soil compactness as a result of trampling causes changes in soil structure and the water–air regime, which in turn affects vegetation status [2, 16–19]. Thus, comprehensive study aimed at revealing the dependence of vegetation, forest litter, and soil status on the level of recreation load for different forest types is urgent.

The aim of this study is to quantitatively evaluate the status parameters of vegetation, forest litter, and soil compactness at different levels of recreation digression in forest parks of Moscow.

MATERIALS AND METHODS

Investigation objects are represented by the ecosystems of two Moscow forest parks: Losinyi Ostrov and Bittsevskii Les. The former is represented by sedge–glague spruce–linden forest on soddy podzolic light loamy soils, and the latter is characterized as sedge–forbs oak–linden forest on soddy podzolic light- and medium-loamy soils.

In each forest park, five test plots (25 × 25 m) were set in similar geomorphologic conditions. The test plots corresponded to five levels of anthropogenic impact determined by the area of the road-path network [13], characterizing five digression stages of biogeocenosis. On the test plots, a geobotanical description of all forest layers was made using conventional methods [9]. Tree status was characterized by combination of parameters proposed by E.G. Mozolevskaya [11]: the status of the assimilation apparatus, debris amount, trunk shape and damage, and the shape of crowns (asymmetry, top drying, crown density, and leaf amount). Then we calculated the number of trees in the following categories of tree status: good, satisfactory, and unsatisfactory (drying and dead) and the number of trees with bare roots. We determined also the characteristics of stable development (CSD) of linden (*Tilia cordata*) according to the approach of V.M. Zakharova and A.T. Chubinishvili [5]. This approach permits the evaluation of environmental quality by five morphometric parameters, characterizing the fluctuating asymmetry of leaf. At each digression stage, 500 laminas were measured.

Ecological–cenotic groups of herb species with similar relations to a combination of ecological factors are widely used in modern investigations. The approaches for the specification of such groups differ. In this study, we have used the idea of ecologic–cenotic groups proposed by A.A. Nitsenko [12], which permits us to assign all grass species to four groups: forest, forest–meadow, meadow, and ruderal. These plant groups are specified in most works devoted to recreation forests [2, 15–19]. The Jaccard similarity coefficient and the Sorensen–Czekanowski index [3], widely used in biogeocenology, have been calculated for the characterization of species-composition similarity of grass communities at different stages of recreation digression. Shade density was determined by a Yu-117 photoelectric light meter at soil level and at a height of 1.5 m above soil surface at 36-fold replication for each test plot.

Forest litter was sampled on each test plot with the use of a 25 × 25 cm frame from paths, a 1-m-wide zone near them, and from the areas beyond the zone of the direct effect of paths. The pronouncement rate of the paths was evaluated by criteria proposed by M.S. Shapochkin [20]. Thickness and reserves of forest litter vary considerably within the area of biogeocenosis, which is related to the effect of the strong phytogenic fields created by edificator trees [7]. For the investigation of forest litter variability, samples were taken from transects (three per test plot) set straight between trees beyond the zones of the direct effect of paths. Samples were taken near the tree, in the middle part of the crown projection and in the space between crowns. We determined the thickness and the ratio between subhorizons of forest litter, reserves of dry substance, composition (parts of crushed (<1cm), active (leafs), and passive (branches, bark, and needles) fractions), moistening, and acidity (the ratio of forest litter to water is 1 : 25). It is known that the recreation effect on soil properties becomes less with depth [8], so we determined the compactness of 0–5-cm-thick soil layer using the conventional method [14].

Statistical treatment of data was performed with the use of the STATISTICA v. 6.0 program. We analyzed stratified samplings drawn with the consideration of part of paths and near-path zones for each test plot.

RESULTS AND DISCUSSION

Successions of Plant Cover with Respect to the Level of Recreation Impact

Tree layer. Recreation exerts various effects on tree status. The mechanical effect causes trunk damage, which results in poorer vital activity and favors the development of diseases and spread of plant pests. Trampling initiates soil compaction and the consequent transformation of water and air regimes and the nutrition conditions of plants. The dependence of the quantitative characteristics of tree status on the level of recreation load is shown by data in Table 1.

At a four- to fivefold increase in recreation load, the proportion of trees in good status drops as the proportion of trees in unsatisfactory status rises, up to 44–46% at DS V. The dynamics of status change depends on the tree species. With a rise in the recreation load, the parameters of tree status change more intensively in the spruce–linden forest of Losinyi Ostrov than in the oak–linden forest of Bittsevskii Les. The proportion of trees in good status drops twofold at the transition to DS III in coniferous–broad-leaved forest and at the transition to DS IV in broad-leaved forest. At DS II in spruce–linden forest, the proportion of trees in unsatisfactory status is 20%, which is almost twice as high as in oak-linden forest at the same recreation impact. This is explained by the lower resistance of coniferous trees to the effect of recreation as compared to deciduous species [2, 6, 17].

Another cause of poorer tree status at recreation load is related to root baring and damage. Tree species whose roots are mainly developed in topsoil horizons,

Table 1. Tree status at different levels of recreation digression

Criteria of tree status (according to [11])	Losinyi Ostrov park (spruce-linden forest)					Bittsevskii Les park (oak-linden forest)				
	I	II	III	IV	V	I	II	III	IV	V
Crown density, %	70–75	65–70	30–35	25–30	20–25	75–80	60–65	50–55	40–45	30–35
Good	26/93	14/56	11/44	8/38	4/18	24/88	24/78	19/66	11/42	6/24
Satisfactory	2/7	6/24	7/28	7/29	8/36	3/12	3/11	5/17	9/35	8/32
Unsatisfactory	0/0	5/20	7/28	8/33	10/46	0/0	3/11	5/17	6/24	11/44
Number of drying trees	0/0	4/16	4/16	5/15	5/24	0/0	2/7	3/10	4/15	9/36
Number of dead trees	0/0	1/4	3/12	3/15	5/24	0/0	1/4	2/7	2/8	2/8
Trees with bare roots	0/0	0/0	1/4	3/13	11/50	0/0	0/0	0/0	1/4	4/16
Total number of tree	28	25	25	24	24	25	27	29	26	25
Characteristic of stable development (CSD) of linden (*Tilia cordata*)										
Mean CSD ($n = 500$)	0.030	0.035	0.039	0.042	0.049	0.028	0.031	0.034	0.041	0.045

Roman figures signify digression stages (here and in the other Tables); number of trees per 100 m^2 is above the line and part, %, is under the line.

suffer severely. Spruce is characterized by a surface root system, so trees with bare roots appear in spruce–linden forest at DS III; at DS V, their proportion is as high as 50%. In oak-linden forest, trees with bare roots appear only at DS IV; at DS V, only 16% appear.

The deterioration of environmental conditions at enhanced recreation load is confirmed by an increase in the CSD of linden (Table 1). Data from dispersion analysis show that the differences between mean CSD ($\alpha = 0.05$) are statistically significant.

At a higher recreation load, crown density drops from 70–80% to 30%, which causes changes in light conditions. Its dependence on recreation load under a tree layer at 1.5 m and at the soil surface is shown in Fig.1. By DS III, illumination at soil level relative to the open surface rises in broad-leaved and coniferous–broad-leaved forests by 13 and 26%, respectively. At DS V, it rises to 47–60% at soil level and to 60% at the height of 1.5 m. Changes in illumination exert an effect on other layers of plant cover.

Shrub-layer status is an important indicator of forest disturbance by recreation [15, 19]. In the forest parks studied, the abundance of undergrowth at the shrub layer remains practically the same at DS IV but drops 3–4 times at DS V. Species diversity changes at a slighter recreation load. At DS I, the shrub layer includes nutwood (*Corylus avellana*) and shade-tolerant species, indicating a slightly disturbed forest: wartybark euonymus (*Euonymus verrucosa*) in Losinyi Ostrov and cranberry tree (*Viburnum opulus*) and button tree (*Lonicera xylostium*) in Bittsevskii Les [15–18]. Modified ecological conditions at DS II result in the disappearance of these sensitive shade-tolerant species, while compact bushes of recreation-resistant nutwood thrive [15–19]. Separate dense shrub groups are formed, and single low (up to 20–50 cm) forms of shade-tolerant species—alder buckthorn (*Frangula*

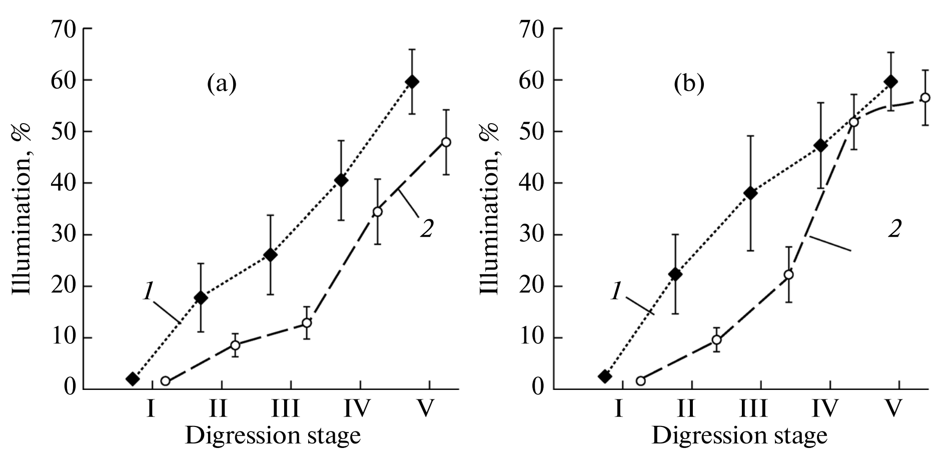

Fig. 1. Correlation between relative illumination and recreation load (*a*) at soil surface and (*b*) at height of 1.5 m: *1*—Losinyi Ostrov; *2*—Bittsevskii Les. Here and further, the confidence interval of mean value is 95%.

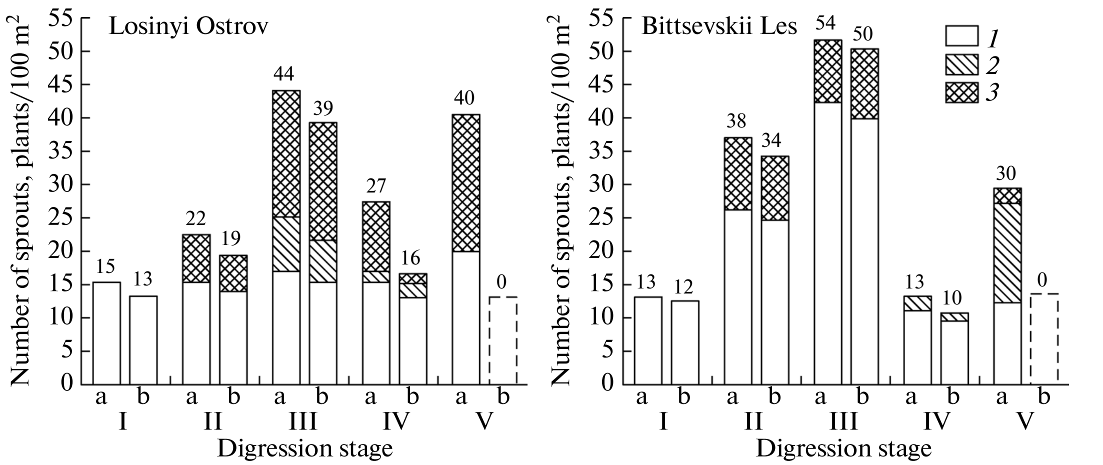

Fig. 2. Number of tree sprouts at different digression stages (*a*) at the beginning and (*b*) in the middle of growing period: *1*—maple (*Acer platanoides*), *2*—oak (*Quercus robur*), and *3*—linden (*Tilia cordata*).

alnus) and button tree—are preserved. At DS III and IV, woodside species (black current and raspberry) invade phytocenoses of Losinyi Ostrov and nutwood remains a dominant species in Bittsevskii Les. In actively visited areas, the shrub layer disappears almost completely, and a bush layer composed of single plants of nutwood is formed.

Undergrowth status in forest parks is evaluated by species diversity, abundance, and morphometric characteristics. At the first three DSs, the undergrowth is predominated by oak (*Quercus robur*), linden (*Tilia cordata*), and maple (*Acer platanoides*). At DS IV, only maple survived in Losinyi Ostrov, while in Bittsevskii Les, all dominants were preserved and a typical representative of woodside and light forest openings—European ash *Fraxinus excelsior*)—appears.

At slight recreation load, DSs I and II, the morphometric parameters of all undergrowth representatives are good: height is up to 5 m and trunk diameter is 3–5 cm. At a higher impact, the undergrowth degrades. At DS III in Losinyi Ostrov and at DS IV in Bittsevskii Les, the part of low undergrowth (of height less than 50 cm) is more than 50%. At DS V, the height drops to 0.3–0.5 m, and trunk diameter does not exceed 0.5 cm.

Undergrowth abundance at DSs I and II is about 10 trees/100 m^2. At a stronger recreation load (DSs III and IV), it rises almost twofold and, at DS V, drops to 2–6 trees/100 m^2.

Our data are confirmed by other investigators, who have revealed a correlation between the enhancement of forest-regeneration processes and recreation load. Light recreation impact favors the disappearance of factors preventing the development of tree seedlings: bush layer becomes thinner, illumination rises, forest litter is destroyed, and moss cover is trampled. Nevertheless, the further enhancement of recreation load causes suppression of undergrowth, which is less recreation-resistant than mature trees [16].

Sprous. The amount of tree sprouts at different DSs at the beginning and in the middle of the growing period is shown in the diagram (Fig. 2). Sprouts are usually allocated in lighter areas without grass cover and forest litter, where the conditions for seed germination are optimum [4, 15, 16]. At DS I of the studied forest parks, sprouts are predominated by maple (12–15 trees/100 m^2) at the beginning and in the middle of the growing period. Optimum conditions for sprout development at DS II and III result in a rise in their species diversity (oak and linden appear) and abundance (two- to fourfold). Recreation-load enhancement causes a decrease in the abundance and species diversity of sprouts: they are mechanically damaged, and some of them die prior to development into undergrowth. At DS V, the amount of sprouts is 30–40 trees/100 m^2 at the beginning of the growing period, and they disappear completely by the end of July.

Grass cover. Four ecologic–cenotic groups of grass are specified in the studied forest parks (Table 2). At a slight recreation load (DSs I and II), grass cover is formed by 9–11 grass species, mainly assigned to the forest ecologic–cenotic group. At medium load, habitat conditions become more variegated, which causes a greater grass-species diversity: forest–meadow, meadow, and ruderal species invade. The greatest species amount for both parks is 24. It is observed when the illumination at soil surface rises to 25% in relation to the open surface. These conditions are created at DS II in Losinyi Ostrov and at DS IV in Bittsevskii Les (Fig. 1).

A further increase in the recreation load results in a drop in species diversity. At greater illumination and soil compactness, grass cover is predominated by light-demanding, trample-tolerant, and mechanical-damage-resistant plants [2, 15–19].

Table 2. Ecologic–cenotic herb groups in areas at different digression stages

Ecologic–cenotic group	Losinyi Ostrov					Bittsevskii Les				
	I	II	III	IV	V	I	II	III	IV	V
Forest	8/89	9/82	10/39	7/58	4/44	10/91	9/90	13/93	8/35	5/45
Forest–meadow	1/11	2/18	3/24	3/25	2/24	1/9	0	1/7	5/24	2/18
Meadow	0	0	0	0	1/11	0	0	0	4/17	1/9
Ruderal	0	0	10/39	2/17	2/24	0	1/10	0	6/26	3/27
Total species per 100 m^2	9	11	24	12	9	11	10	14	24	11

Roman figures signify digression stages (here and in the other Tables); number of trees per 100 m^2 is above the line and part, %, is under the line.

Table 3. Similarity coefficients of species composition of grass communities at different digression stages

Digression stage	Losinyi Ostrov										Bittsevskii Les									
	Jaccard similarity coefficient					Sorensen–Czekanowski index of species composition similarity					Jaccard similarity coefficient					Sorensen–Czekanowski index of species composition similarity				
	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V	I	II	III	IV	V
I	–	0.25	0.03	0.24	0.06	–	0.4	0.06	0.38	0.11	–	0.62	0.56	0.24	0.24	–	0.76	0.72	0.35	0.36
II	0.25	–	0.1	0.24	0.11	0.4	–	0.18	0.35	0.2	0.62	–	0.41	0.24	0.11	0.76	–	0.58	0.36	0.19
III	0.03	0.1	–	0.17	0.14	0.06	0.18	–	0.29	0.25	0.56	0.41	–	0.19	0.14	0.72	0.58	–	0.32	0.24
IV	0.24	0.24	0.17	–	0.11	0.38	0.35	0.29	–	0.19	0.24	0.24	0.19	–	0.26	0.35	0.36	0.32	–	0.41
V	0.06	0.11	0.14	0.11	–	0.11	0.2	0.25	0.19	–	0.24	0.11	0.14	0.26	–	0.36	0.19	0.24	0.41	–

At the initial DSs, glague (*Aegopodium podagraria*), sedge (*Carex pilosa*), and yellow archangel (*Lamium galeobdolon*) predominate. Their total projective cover is 50–60%. At medium recreation load, their participation in total projective cover drops to 10–15%, and they disappear almost completely in commonly visited areas. At DS IV, the proportion of species resistant to mechanical damage and soil compacting increases. These are impatience (*Impatiens noli-tangere* and *I. parviflora*), herb bennet (*Geum urbanum*), common nettle (*Urtica dioica*), bugle (*Ajuga reptance*), and May lily (*Convallaria majalis*). At DS V, most recreation-resistant species remain: common dandelion (*Taraxacum oficinale*), common plantain (*Plantago major*), herb bennet, and impatience (*Impatiens parviflora*). Phenological phases of most species at slight digression include blooming and defloration, while at DSs III and IV, only the vegetation stage is seen.

A similarity analysis of the species composition of grass communities at various digression stages (Table 3) shows that a sharp drop in similarity is seen at the transition to the digression stage with highest species diversity (DS III for Losinyi Ostrov and DS IV for Bittsevskii Les). Differences in species composition of grass layer at various DSs are greater in spruce–broad-leaved forest than in broad-leaved forest.

Moss layer in the studied area is fragmentary. At the transition from DS I to DS II, the area of moss spots rises from 3–5% to 7–10%. At DS IV and V, recreation-sensitive mosses disappear, which is confirmed by published data [15–18].

Variations in Forest Litter with Respect to Recreation Impact

Forest litter is the most recreation-sensitive component of the forest ecosystem. Its transformation is determined by integral parameters, as follows: morphological structure, thickness, and reserve. Recreation causes changes in the amount of forest litter subhorizons. At initial DSs, it is categorized as the humified or fermentative type (according to [1]). At DSs III and IV, it is of the destructive type and is represented by one layer of undecomposed plant remainders.

At DSs I and II, forest-litter thickness varies within 1–5 cm and averages to 2–3 cm. By DS V, its thickness drops to 0.5 cm and it becomes fragmentary.

Data on forest-litter reserves at various DSs are shown in Fig. 3. Statistical analysis shows that DSs II and III are characterized by a rise in spatial variations in forest litter reserves. At transition from DS I to DSs II and III, dispersion rises 5–7 times, so the increase

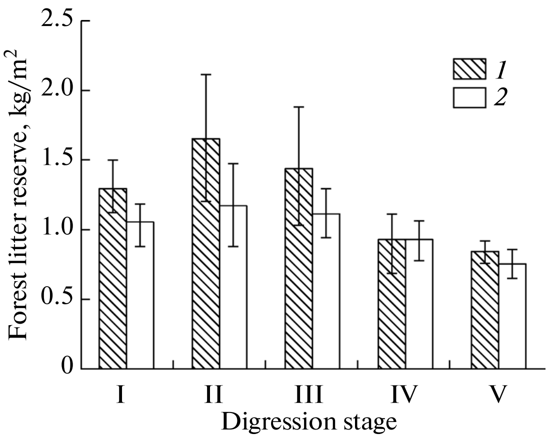

Fig. 3. Correlation between forest litter reserves and recreation impact: *1*—Losinyi Ostrov; *2*—Bittsevskii Les; confidence interval of mean value is 95%.

in forest litter reserves at these stages is statistically insignificant. A statistically significant increase in forest litter reserves, of 25–33%, is only seen at DS V.

The fraction composition of forest litter is transformed with the rise in recreation load (Fig. 4). The active fraction predominates at the four initial DSs, though its part drops in opposition to the digression impact from 73–82% to 49–55%. At DS V, the passive fraction predominates. In trampling, forest litter is ground, and the proportion of the crushed fraction rises five times in the spruce–broad-leaved forest of Losinyi Ostrov and 9 times in Bittsevskii Les.

The data testify to a statistically significant increase in moistening (in the dry period) and a drop in the acidity of forest litter at a greater recreation load (Table 4). A drop in acidity is related to the input of atmospheric technogenic dust containing carbonates and deicing reagents.

Soil Compactness Succession with Respect to Recreation Load

Numerous data testify to the considerable effect of recreation on the properties of forest soils [2, 7, 16, 19, 21, 22]. The dependence of soil compactness on recreation load merits special attention, because it determines the water, air, and nutrition regimes of plants and development conditions of biological processes in soils. Trampling in recreation forests causes compacting of the top mineral soil layer. The process is enhanced by forest litter destruction. Soils on paths are especially compacted.

The dependence of soil compacting on the types of paths is shown by the data in Table 5. On slightly pronounced paths, a statistically significant increase in soil compactness is only seen in the 0–5-cm-thick layer. On medium pronounced paths, trampling causes a rise in compactness to a depth of 20 cm for medium loamy soils in Bittsevskii Les and only to a depth of 5 cm for light soils of Losinyi Ostrov. On well-pronounced paths, compacting is revealed to a depth of 10–20 cm in both cases. Compactness variation of the 0–5-cm-thick mineral layer of loamy soddy podzolic soils with respect to digression stage is shown in Fig. 5.

Recreation results in an increase in soil compactness by 0.24–0.28 g/cm^3. A statistically significant rise in soil compactness is seen at transition to DS IV in spruce-linden forest of the Losinyi Ostrov park, and at greater load (DS V) in the oak–linden forest of Bitt-

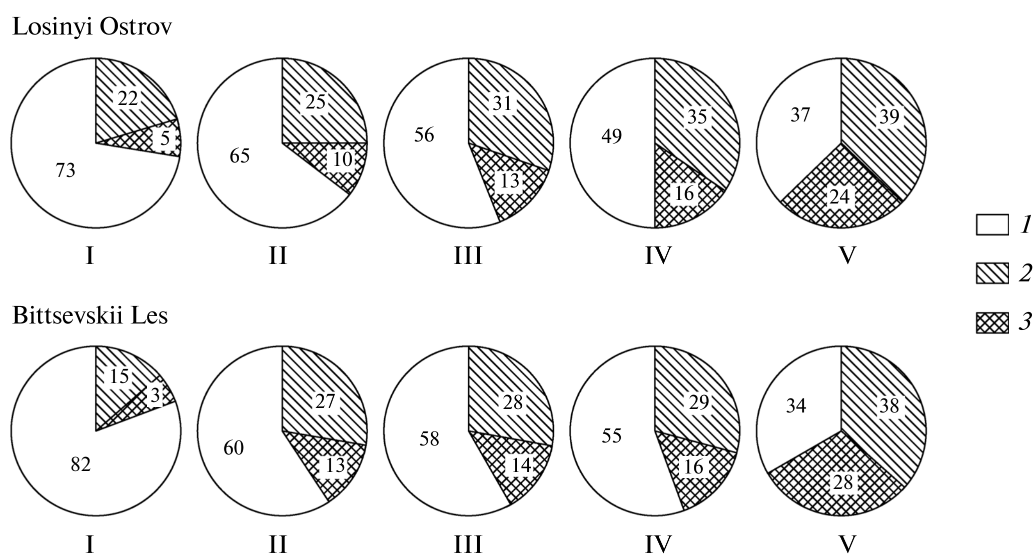

Fig. 4. Variations in fractional composition of forest litter with respect to recreation load: *1*—part of active fraction (leafs), *2*—part of passive fraction (brunches, bark, and needles), *3*—part of crushed fraction (<1cm).

Table 4. Forest-litter moistening and acidity at different recreation load

Digression stage	Losinyi Ostrov					Bittsevskii Les				
	I	II	III	IV	V	I	II	III	IV	V
Moisture content	20.0 ± 2.3	24.0 ± 2.2	24.8 ± 2.9	28.2 ± 2.2	30.4 ± 2.1	19.5 ± 2.5	24.3 ± 3.1	24.4 ± 2.9	24.3 ± 2.8	27 ± 2.3
Soil reaction, pH	5.49 ± 0.08	5.65 ± 0.07	5.7 ± 0.07	5.7 ± 0.09	5.9 ± 0.06	5.75 ± 0.09	5.77 ± 0.12	5.78 ± 0.09	5.9 ± 0.09	6.00 ± 0.07

Roman figures signify digression stages (here and in the other Tables); number of trees per 100 m^2 is above the line and part, %, is under the line.

Table 5. Soil compactness on paths of different types

Layer, cm	Slightly pronounced type		Medium pronounced type		Well pronounced type	
	path	at a distance of 1 m from the path	path	at a distance of 1 m from the path	path	at a distance of 1 m from the path
			Bittsevskii Les			
0–5	**1.18 ± 0.078**	**1.02 ± 0.073**	**1.24 ± 0.084**	**1.03 ± 0.084**	**1.42 ± 0.075**	**1.12 ± 0.041**
10–20	1.2 ± 0.043	1.24 ± 0.029	**1.26 ± 0.024**	**1.15 ± 0.032**	**1.5 ± 0.034**	**1.24 ± 0.034**
			Losinyi Ostrov			
0–5	**1.07 ± 0.031**	**0.93 ± 0.055**	**1.32 ± 0.059**	**1.01 ± 0.092**	**1.39 ± 0.077**	**1.05 ± 0.043**
10–20	1.33 ± 0.008	1.36 ± 0.019	1.46 ± 0.105	1.31 ± 0.085	**1.72 ± 0.045**	**1.45 ± 0.072**

Statistically significant differences ($\alpha = 0.05$) are given in bold type.

sevskii Les. Forest herb species disappear at soil compactness levels of 1.2–1.3 g/cm^3 [18]. The optimum soil compactness is 0.9–1.15 for coniferous trees, 0.9–1.45 for oak, and 1–1.45 g/cm^3 for linden [10].

In the oak–linden forest of Bittsevskii Les, soil compactness at DS V is 1.25–1.27 g/cm^3 at a depth up to 20 cm. These conditions are optimum for oak and linden, but may be critical for some forest herbs. In the spruce–linden forest of Losinyi Ostrov, soil compactness at the layers of 5–10 and 10–20 cm exceeds the highest limit of optimum compactness for linden at DS IV, though it is categorized as the most compaction-tolerant tree species.

CONCLUSIONS

The quantitative characteristics of plant cover, forest litter, and soil status in forest parks of Moscow are transformed under the effect of recreation. Plant cover is the most sensitive component of forest ecosystems. Statistically significant changes in the stability index of linden calculated by the fluctuating asymmetry of leaf is already seen at DS II. Oak–linden forests are more recreation-resistant than spruce–linden ones. The status of more than half of the trees in the former remains good up to DS IV; while in the latter, only 44% have this status from DS III.

The deterioration of tree status causes a drop in crown density from 70–80% to 30%, which results in higher illumination (it rises 30 times at DS V).

Recreation favors the succession of grass layer. The similarity of species composition of grass communities at different DSs decreases especially quickly at transition to DS with greatest species diversity. This is DS III in spruce–broad-leaved forest of Losinyi Ostrov and DS IV in broad-leaved forest of Bittsevskii Les.

Recreation exerts a considerable effect on forest litter: its type, reserves, and fractional composition differ. Forest litter of humified and fermentative types at low recreation gives way to destructive forest litter at DSs III and IV. An increase in the recreation load is

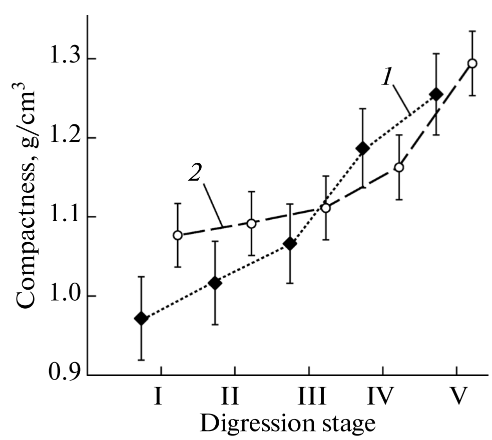

Fig. 5. Dependence of soil compactness on recreation load: *1*—Losinyi Ostrov; *2*—Bittsevskii Les.

accompanied by the increasing spatial variability of its reserves. At the transition from DS I to DSs II and III, dispersion rises 5–7 times, and a statistically significant drop in forest litter reserve by 25–33% is only seen at DS V. As a result of grinding and trampling, the fractional composition of forest litter is characterized by an increase in the part of crushed fraction fivefold in the spruce–broad-leaved forest of Losinyi Ostrov and ninefold in the broad-leaved forest of Bittsevskii Les. The input of atmospheric technogenic dust and deicing reagents cause a smaller acidity of forest litter (pH=5.9–6.0 at DS V).

Forest-litter destruction favors soil compacting. By DS V, the compactness of top mineral layer rises by 0.24–0.28 g/cm^3. A statistically significant increase in soil compactness is already seen at the transition to DS IV in the spruce-linden forest of Losinyi Ostrov and only at DS V in the oak–linden forest of Bittsevskii Les. The compactness of medium loamy soil in the oak–linden forest of Bittsevskii Les does not exceed 1.3 g/cm^3 to a depth of 20 cm at DS V. This is an optimum condition for oak and linden, but it may be critical for some forest herbs. In the spruce–linden forest of Losinyi Ostrov, the compactness of light loamy soils in the root zone is already higher than optimum for linden—the most compacting-resistant tree species—at DS IV.

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