The influence of recreation on changes in the vital conditions of soil invertebrates

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Abstract. An assessment of the state of soil invertebrate complex, litter horizons, and soddy-podzolic soils (Albic Retisols) in Moscow forest parks (“Bitsevskii Forest” and “Losinyi Ostrov”) as a function of the level of recreational loads is presented. A clear pattern has been established for the deterioration of the soil invertebrates as the recreational load increases. This occurs as a result of changes in their habitat conditions, largely due to changes in the soil water regime and soil invertebrate feeding conditions. The abundance, biomass and diversity of soil invertebrates decrease by a factor of 2–2.5 under the influence of the recreational load. The condition of soil invertebrates is a sensitive indicator, which depends on the conditions of their habitat and is mainly determined by changes in the characteristics of the litter and soil properties.

1. Introduction
Recreation affects not only the plant cover and soil properties, but also the state of the soil invertebrate complex. It contributes to the compaction of the soil, the growth of the footpath network and the formation of a special structure of soil cover, consisting of the alternation of dense footpaths and areas outside the footpaths. The formed footpath network violates the integrity of forest biogeocenoses, the spatial continuity of grass cover, litter and soil, leading primarily to changes in soil invertebrate populations as a result of fragmented habitats of living organisms. In recreational forests soil invertebrates are directly affected, which is expressed mainly in their mechanical destruction and mediated through the transformation of their ecological niches (reduction of living space and food supply). The abundance, biomass and diversity of soil invertebrates can differ by 20 times their initial values in urban forest parks with an increase in recreational load [1-5].

The goal of this work is to assess changes in the living conditions of soil invertebrates under the influence of recreation.

2. Objects and methods
The objects of study were soil invertebrates of two forest Moscow parks: “Losinyi Ostrov” and “Bitsevskii Forest”. We studied the ecosystems of the spruce-linden forest on sod-podzolic light loamy soils in the “Losinyi Ostrov” forest park (N55.830861°, E37.794213°) and the oak-linden forest on sod-podzolic medium loamy soils in the “Bitsevskii forest” (N55.620813°, E37.534794°). According to the WRB (2014) the studied soils belong to Albic Retisols [6]. There were five sampling plots 25×25 m in each ecosystem corresponding to different levels of recreational load, determined by the share of the footpath network, characterizing each of the five stages of recreational digression [7].
When studying the dependence of changes in soil properties on the level of recreational impact, it is important to consider differences in the natural spatial heterogeneity of sample plots at different stages of digression, as well as varying degrees of change in soil properties on footpaths, near footpaths and on sections outside the footpaths.

In this regard, on each trial plot soil samples were taken in three zones: on the footpaths, in the areas along the footpaths (at a distance of up to 100 cm) and on the territory outside the direct influence of the footpaths. The background area was sample plots of the first stage of digression.

We investigated the characteristics of the litter (type, stock, fractional composition) and soil properties (pH$_{\text{water}}$, electrical conductivity, organic carbon content, hardness, density and aggregate composition) using the generally accepted methods [8, 9]. Determination for the abundance, group composition (diversity) and biomass of the soil mesofauna was made in 3-fold repetition in the litter, 0-10 and 10-20 cm soil layers using manual disassembly of monoliths with an area of 1/16 m$^2$ [10]. Statistical analysis of the data was carried out in the STATISTICA package (data analysis software system). Analyzed systematic sampling, considering the uneven distribution of recreational load in each trial area.

3. Results and discussion
Among the soil horizons, the litter is the first to take on a recreational load. The type, stocks and fractional composition of the litter change under the influence of recreation. Human trampling negatively affects litter. Litter is compacted, frayed and ground. The crushed litter is blown out by the wind, it is easily washed off by surface runoff waters, and a large fraction is moved by pedestrians - its heterogeneity increases. The increase in recreational load determines a statistically significant decrease in litter stocks by 25-33% to the V stage of digression and an increase the share of litter crushed fraction because of human trampling. The percentage of the crushed fraction increases by 4 times in the coniferous-deciduous forest of the “Losinyi Ostrov”, and by 7 times in the deciduous forest of the “Bitsevskii Forest”.

Some of the main negative consequences of recreation are soil compaction and violation of its structure, which cause a change in the physical properties of the soil. These violations in the conditions of the city are complemented by the entry into the landscapes of products of urbotechnogenesis (atmospheric dust, anti-icing agents, various carbon-containing compounds). In addition, due to grinding and trapping fragments of litter, the organic material of the litter is moved to the upper mineral layer. All this leads to a change in the soil properties (table 1).

In the upper five-centimeter mineral layer of the soil, the hardness increases by more than 2.5 times, the density by 0.21-0.28 g/cm$^3$, and the share of agronomically valuable aggregates and the coefficient of structure decreases by 2 and more than 4 times, respectively. In some cases, the physical properties reach their critical values, which are unfavorable for the vital activity of living organisms. Not only physical, but also chemical properties of soils change. The content of organic carbon increases from 1.7-2% to 2.9-3.3%. The conductivity increases by 2-3 times, and the acidity decreases. During the transition to the V stage of digression, the pH$_{\text{water}}$ value increases from 4.3 to 5.1 in the soils of the spruce-linden forest of the “Losinyi Ostrov” and from 5.2 to 5.6 in the soils of the oak-linden of the “Bitsevskii Forest”.

Under the influence of increasing recreational effects, the state of soil invertebrates changes, which is a consequence of the transformation of their habitat conditions, largely due to changes in the thermal, water-air regime of the soil and feeding conditions. Such changes affect the activity and orientation of biological processes. The condition of soil invertebrates is an integral characteristic of environmental conditions, as a result of which there are many variants of their reactions to recreational effects, depending on its duration and intensity.

In zones of forest parks that are not experiencing recreational load, the density and biomass of the mesofauna are about the same (450–500 specimens/m$^2$ and 160–170 g/m$^2$). It is most abundant in the 0–10 cm soil layer (up to 50–75%) and litter (25–55%). Minor differences are due to the properties of
the soils, which in the “Losinyi Ostrov” compared to the “Bitsevskii Forest” have a lighter grain size distribution, greater acidity and lower organic carbon content.

Table 1. Physical and chemical properties of the soils at different stages of recreational degradation.

| Soil properties       | Degradation stage | Losinyi Ostrov | II | III | IV | V |
|-----------------------|-------------------|----------------|----|-----|----|----|
|                       |                   |                |    |     |    |    |
| n                     | 18                | 22             | 24 | 29  | 54 |
| Bulk density, g/cm³   | 0.97±0.05         | 1.02±0.05      | 1.07±0.07 | 1.18±0.06 | 1.25±0.05 |
| Penetration resistance, MPa | 1.1±0.33        | 1.8±0.36       | 2.5±0.28 | 2.6±0.29 | 2.9±0.23 |
| Aggregation coefficient | 3.9±0.38        | 2.7±0.43       | 1.5±0.29 | 1.1±0.24 | 1.0±0.22 |
| Corg, %               | 1.77±0.25         | 1.92±0.29      | 2.56±0.39 | 2.62±0.26 | 2.92±0.38 |
| Ec, dS/m              | 0.28±0.03         | 0.35±0.04      | 0.37±0.07 | 0.46±0.08 | 0.56±0.1  |
| pH_water              | 4.26±0.16         | 4.66±0.15      | 4.66±0.14 | 4.95±0.14 | 5.05±0.11 |

| Soil properties       | Degradation stage | Bitsevskii Forest | II | III | IV | V |
|-----------------------|-------------------|-------------------|----|-----|----|----|
|                       |                   |                   |    |     |    |    |
| n                     | 17                | 21                | 22 | 31  | 42 |
| Bulk density, g/cm³   | 1.08±0.05         | 1.09±0.06         | 1.11±0.06 | 1.16±0.05 | 1.29±0.05 |
| Penetration resistance, MPa | 1.8±0.37        | 2.5±0.33         | 2.7±0.38 | 2.9±0.32 | 3.8±0.31 |
| Aggregation coefficient | 4.9±0.45        | 3.3±0.44         | 3.1±0.43 | 2.1±0.24 | 1.0±0.22 |
| Corg, %               | 2.01±0.25         | 2.45±0.3         | 2.73±0.22 | 3.1±0.4  | 3.29±0.41 |
| Ec, dS/m              | 0.2±0.02          | 0.22±0.03        | 0.23±0.03 | 0.33±0.12 | 0.48±0.12 |
| pH_water              | 5.2±0.09          | 5.26±0.1         | 5.33±0.12 | 5.37±0.1  | 5.62±0.1  |

Note: X ± Δ - is mean ± confidence interval (95%).

As the recreational load increases, the abundance and biomass of soil invertebrates decreases (figure 1).

The abundance to the stage of digression decreases 1.3-1.4 times, which is mainly due to the inhibition of the invertebrate litter complex. At the V stage of digression, the total abundance of soil invertebrates decreases 2.1-2.3 times, most noticeably in the litter: in “Losinyi Ostrov” in 4 times, and in “Bitsevskii Forest” - 7 times. Thus, with an increase in the recreational load, the relative share of the mesofauna in the litter decreases, and in the mineral layers of the soil increases.

A statistically significant decrease in the total biomass of soil invertebrates was noted already at stage II of digression, and when going to stage V, it decreases by 2–2.5 times (figure 1).

Representatives of 6 classes of soil invertebrates were found on the studied objects, among which individuals of 18 systematic groups and representatives of all types of nutrition were identified. At I-III stages of digression, 13-15 systematic groups of invertebrates are encountered. As the recreational load increases (IV-V stages of digression), their abundance decreases by 3–4 groups. However, in different horizons, the patterns of change in the abundance of groups are unequal: the greatest changes are noted in the litter, where their abundance decreases from 10–12 to 4–5.

As the recreational load increases, the share of various classes of soil invertebrates changes - the ratio of individuals performing various locomotor and trophic functions changes and, as a result, the structural and functional organization of the soil mesofauna is transformed. The proportion of Oligochaeta increases from 17-22 to 53-77% and the proportions of arachnids, insects and millipedes decrease by a factor of 2-3. A decrease in the diversity of soil invertebrates is evidenced by a decrease in the value of the Shannon-Weaver index from 2.2 in stage I to 1.7 and 1.0 to stage V of digression, respectively, in “Losinyi Ostrov” and “Bitsevskii Forest”.

3
The increase in the proportion of earthworms is due to the presence on the footpaths of a fragmented, moist, loose layer consisting of a poorly decomposed depressed organic litter material with a thickness of 0.5-1 cm, which serves as a favorable substrate for their nutrition.

It should be noted that changes in most soil properties are less pronounced compared to indicators of the state of the complex of soil invertebrates, which is probably due to their high sensitivity to changes in environmental conditions during recreation.

Among the properties of the soils, which, apparently, have the greatest impact on soil invertebrates, significantly changing with a small recreational load (stage II-III of digression), stand out hardness and indicators of the structural state. In addition, a significant contribution is made by changing the characteristics of the litter. The greatest changes in the community of soil invertebrates are marked on the footpaths. The patterns of change in the state of soil invertebrates in the studied forest parks are the same: the wider and better the footpath is, the more these indicators decrease on the footpath relative to the background. The width zone, in which the deterioration of the soil mesofauna is traced, depends on the type of footpath. For weakly expressed footpaths, it is 20 cm, moderately expressed - 50 cm, and along well-marked footpaths - increases to 100 cm.

4. Conclusions
A clear pattern has been established for the deterioration of the soil invertebrates as the recreational load increases as a result of changes in their habitat conditions. The complex of soil invertebrates of the litter horizon changes most noticeably with increasing recreational load. A significant transformation of the state of soil invertebrates, even in the early stages of digression, makes them a very sensitive indicator of the recreational load and changes in environmental conditions.

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