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Establishment of a Landfill Impact Zone on Soils Using Structural and Functional Modifications of Microbial Communities

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Abstract—A number of structural and functional parameters of microbial communities have been applied for ecological monitoring of soils located in nearby landfills. The difference in sensitivities to pollution between different microbial indices was shown. A landfill impact zone in the direction of pollution migration was established using the total disturbance index of habitat microbial communities.

Key words: biomonitoring, pollution, micromycets, soils, microbial communities, solid waste.
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INTRODUCTION

Environmental monitoring of waste disposal sites and adjacent territories is regulated by the laws of the Russian Federation. According to the Federal Law of 24 June 1998 no. 89-FZ "On Production and Consumption Waste," examination of environmental waste hazards should include a wide range of abiotic and biotic parameters. An urgent problem is the identification of zones of actual and potential ecological risk from the waste industry [13].

Effectiveness and informativity of indices used for zoning of the territory adjacent to waste disposal sites (WDS) are distinct from each other. Soil microbial community analysis is considered to be one of the most complex parts of local ecological monitoring [10]. At the same time, it is essential since it is the microorganisms that participate in the cleaning of soil, the transformation of organic matter and formation of humus, and they are responsible for soil fertility and quality [5]. Soil microorganisms are sensitive indicators of various modifications occurring in the environment [11]. The dynamic nature of most microbial indices is extremely high, due to which the intensive study of their efficiency is required to estimate the environmental effects that occur from such a complex object as a landfill.

The negative impact of WDS is a very serious environmental problem in Russia. The Moscow region alone has 59 landfills, not including multiple rubbish dumps and junk areas [4]. A distinct feature of the landfills is the multicomponent composition of the major pollutant, leachate, which is an aqueous solution saturated with waste degradation products.

We have attempted to perform zoning of the territory adjacent to the landfill, in accordance with variability of the structural and functional parameters of microbial communities.

MATERIALS AND METHODS

The study was performed on the territory of one of the landfills of the Moscow region. According to environmental requirements, it is classified as potentially hazardous [3, 7, 12]. Chemical analysis of soils and several other environmental components (water, bottom deposits) have been performed over the last three years. We found that the landfill leachate has a high time-varying content of a number of pollutants, which exceed the maximum permissible concentration (MPC) for domestic water by factors of tens and hundreds on average (mercury, chrome, manganese, and other toxic elements buried in the landfill) and spread through adjacent draining trenches, water streams, and the river (Fig. 1). Soil cover near the landfill is represented by shallow soddy podzolic middle loam and soddy gley soils. The sanitary protection zone of the landfill (500 m) includes the land belonging to forest reserves. No systematic biological study of the territory around the landfill was performed previously.

The selected testing guideline of surface–mixed soil samples (transects) coincides with the major track of southeast migration of contamination in water streams. The material for biological examination includes soil samples, collected at the following points:

1—the filled soil collected on the surface of the landfill;

2—10 m south of the landfill, the leachate discharge zone into draining trenches; soils are regularly impounded by leachate;

3—30 m north of the landfill; road to landfill;

4–9—250, 500, 950, 1500, 2000, and 3000 m away from the landfill (by water streams);

Background – background soil not affected by the landfill, highway, railway, or adjacent plants.

To estimate structural and functional indices of microbial community development, both traditional and new research methods were used. The total number of fungi was determined by specimen inoculation in Petri dishes on Chapek agar media with a low pH level to suppress bacterial growth [9]. The composition and structure of the soil microbial community was determined by gas chromatography/mass spectrometry (GC/MS) [1, 15]. The fungal biomass structure (spore–mycelial ratio) was determined using lumines-

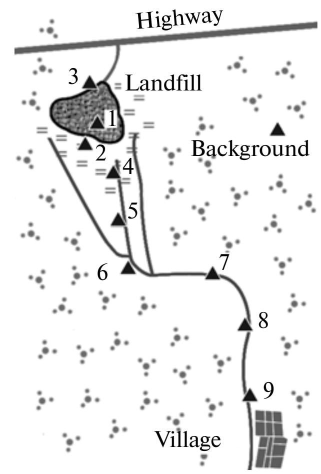

Fig. 1. Landfill location plan and points of sample collection.

Structural and functional parameters of soil microbiota at a distance from the landfill and deviation from background values

Microbiological indices	Soil samples collected near the landfill									
	1	2	3	250 m	500 m	950 m	1500 m	2000 m	3000 m	background
Total bacterial biomass (GC/MS)										
BM, cells/g of soil	23.49	64.63	74.37	50.83	43.90	52.49	32.79	39.65	47.37	64.13
Deviation from background, times	0.37	1.01	1.16	0.79	0.68	0.82	0.51	0.62	0.74	
Shannon species diversity of bacterial biomass (GC/MS)										
Shannon Index, I	1.06	1.84	1.78	1.22	1.37	1.40	1.17	1.23	1.07	1.59
Deviation from background, times	0.66	1.15	1.12	0.77	0.86	0.88	0.74	0.77	0.67	
Total fungal biomass (GC/MS)										
FB, μg/g of soil	5.61	39.02	41.05	37.54	42.61	33.94	14.11	11.94	9.92	13.28
Deviation from background, times	0.42	2.93	3.09	2.83	3.21	2.55	1.06	0.89	0.75	
Spore fraction in fungal biomass (luminescent microscopy)										
Spore fraction, %	99.7	95.04	96.34	97.25	98.27	95.03	94.19	98.99	99.96	88.76
Deviation from background, times	1.12	1.07	1.08	1.09	1.10	1.07	1.06	1.11	1.12	
Soil respiration (gas chromatography)										
CO_2 emission, μmol/g of soil h	0.43	1.85	1.56	1.83	1.76	0.90	1.50	1.17	0.66	1.14
Deviation from background, times	0.37	1.62	1.37	1.61	1.54	0.79	1.31	1.02	0.58	
Soil fungi population (luminescent microscopy)										
FP_m, propagules × 10^6/g of soil	5.15	3.96	2.12	4.25	3.73	3.18	1.55	3.25	4.41	1.30
Deviation from background, times	3.96	3.05	1.63	3.27	2.87	2.45	1.19	2.50	3.39	
Soil fungi population (Chapek agar inoculation)										
FP_i CFU × 10^3/g of soil	0.83	45.83	9.67	8.33	14.67	9.50	32.67	35.33	5.50	8.00
Deviation from background, times	0.10	5.73	1.21	1.04	1.83	1.19	4.08	4.42	0.69	
Deviation index										
$K = FP_m/FP_i$ times × 10^3	6.20	0.08	0.22	0.51	0.25	0.33	0.05	0.09	0.80	0.16
Deviation from background, times	38.75	0.50	1.37	3.19	1.56	2.06	0.31	0.56	5.00	

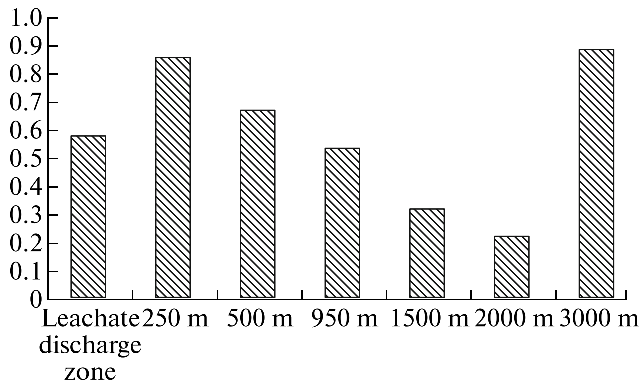

Fig. 2. Disturbance index (*D*) of soils collected at various distances from the landfill.

cence microscopy by staining soil suspensions with a fungi-specific dye, Fluorescent Brightener 28. Respiration activity was determined by carbon dioxide emission using a CrystalLux-4000M gas chromatograph and the thermal response detection [9].

RESULTS AND DISCUSSION

Based on previous chemical analysis, the total soil pollution index (*Zc*) as described in Sayet was calculated [2, 8], the values of which at 300 and 500 m from the landfill suggest dangerous pollution levels (61.5 and 61.1, respectively), while at 950 m the pollution level is permissible (*Zc* is 2.2). Soil samples collected 1 km away from the landfill contain an increased amount of acid-soluble forms of copper and nickel, up to a MPC of 7.

Investigation of soil microbiota at various distances from the landfill demonstrates that several functional and structural indices are good markers of modifications occurring in bacterial and fungal communities in the studied direction from the landfill. Furthermore, deviations of various microbial indices compared to the background (conditionally undisturbed) are significantly different (table).

The influence of the landfill as an environmental pollutant on adjacent soils is found to stimulate the soil microbiota development, growth of population, biomass and biological diversity (shown by the biomass of certain species), increased spore fungi biomass, and activation of soil respiration. The methods applied here determine the impact of the landfill at different distances. Based on the degree of difference in the described indices from the background at different locations down gradient of the landfill, we arranged them from decreasing soil sensitivity to leachate pollution as follows: relative population of soil fungi calculated directly (luminescent microscopy) or by inoculation; total fungi biomass > soil respiration; species diversity of bacterial biomass; total bacterial biomass > spore fraction in the fungal biomass. According to [6], the ratio of CG_M to CG_P reveals a high negative correlation with the soil content of heavy metals representing the fungal fraction, which is not inoculated onto nutrient media.

To generalize the obtained data and zone the territory, the disturbance index (*D*) was calculated, representing the deviation of the biotic indices population in the studied samples from the background by the following formula:

$$D = \frac{\sum_{i=1}^{n}\left|1 - \frac{C}{C_{\text{back}}}\right|}{n},$$

where C is the absolute value of the index and C_{back} is its background value. [*D*] is calculated using the multiplicity of the deviation of biological parameters from the background (both negative and positive values) by the formula, reflecting the total degree of deviation of biological response from the background in the range from 0 to 1. Figure 2 demonstrates the sum values of [*D*] for soils, which were selected along the distance gradient from the landfill.

If, according to *Zc*, the total soil pollution by heavy metals at 950 m (in the predominant direction of pollutant migration) is permissible [2], a 30% difference from the background (conforming with the norms for total indices [14]) can be detected by biological methods only at 1500 m from the landfill, i.e., outside the sanitary protection zone of the landfill. The high value of [*D*] at 3000 m is likely to be connected with the fact that there is a water flow into the river that passes through village sites and farms.

Thus, microbiological techniques prove more sensitive to environmental pollution. The modification of the ecological state of soils described above provide a clear description of the modification rate and give better information than costly chemical analysis.

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