Biodiversity of Algae and Cyanobacteria in Soils of Moscow

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Abstract. Biodiversity and structure of algal–cyanobacterial communities were studied in soils of background plots in the undisturbed morainic landscape of Moscow region and in urban soils of different land-use zones in two administrative districts of Moscow. Their specific features were identified, and their relationships with the major directions of transformation of the properties of urban soils were shown.

Keywords: Algae · Cyanobacteria · Biodiversity · Soils · Pollution
Heavy Metals (HMs) · Deicing reagents

1 Introduction

Microscopic algae and cyanobacteria are soil indispensable inhabitants which form algal-cyanobacterial communities representing an obligatory part of any phytocenosis. Soil algae and cyanobacteria are very sensitive to soil properties transformation and react on it by biodiversity, composition and structure transformations [1]. The strength of these transformations indicates the degree of integral anthropogenic impact on soils, this opportunity is applied in urban landscapes bioindicational researches [2–5].

The aim of this research was to determine the major factors that control algal-cyanobacterial communities in urban soils. The city of Moscow was chosen and urban soils were compared to soils in background landscapes.

It includes the following tasks:

(1) to obtain data on the physicochemical properties of undisturbed soils in background morainic landscapes of Moscow region and to characterize the main directions of their anthropogenic transformation in the urban environment;
(2) to characterize algal–cyanobacterial communities of background and urban soils; and
(3) to identify factors affecting algal–cyanobacterial communities biodiversity, composition, and structure.

V. Vasenev et al. (Eds.): SUITMA 2017, SPRINGERGEOGR, pp. 135–144, 2019.
https://doi.org/10.1007/978-3-319-89602-1_17

2 Study Area and Methods

2.1 Study Area

The study area is found in the taiga zone on the Smolensk−Moscow Upland in the central part of the East European Plain [4]. It is characterized by the moderately continental climate, the mean annual temperature is +5.4 °C and the mean annual precipitation is 700 mm. The summer is moderately warm, the winter is moderately cold; the frosty period (with the mean daily temperature below −5 °C) lasts about 100 days; the average snow thickness is 40−45 cm [4, 6].

The background site was located 40 km to the west of Moscow on the morainic plain with native soddy-podzolic soils (Glossic Retisols) under spruce or mixed forests with herbs and mosses in the ground cover and with cultivated soddy-podzolic soils (Glossic Retisols (Aric)) under sown grass meadows.

In Moscow the research was carried out on the territory of two administrative districts − North-Western and Western − in different land-use zones (recreational, traffic and residential). Land-use zones differ according to the level of anthropogenic impact [7]. The recreational zone is a city park with slightly disturbed soddy-podzolic soils (Glossic Retisols) under forest phytocenoses (herbaceous pine forest, yellow archangel-herbaceous birch−linden forest, yellow archangel maple forest with pine) [4]. The traffic zone is roads and adjoining areas, the residential zone - apartment buildings. Among the studied urban soils, urbanozems (Urbic Technosols) predominate [8].

2.2 Methods

Field Research. Samples for algological examination were taken from the upper soil layer (0–5 cm) in spring, soon after the snowmelt season (April–the beginning of May) both in the background site and in different land-use zones of the city. In the recreational zone samples were taken at a distance 1–3 m from walking roads, in the traffic zone – 1–3 m from the highways. In the residential zone, samples were taken from the lawns near sidewalks, near garbage containers, and near parking lots.

Studying Algae and Cyanobacteria. Species biodiversity of soil algae and cyanobacteria was studied by standard methods of soil algology – in soil cultures with fouling glasses and in liquid cultures on the Bold medium [9, 10]. The cultures were grown under daylight at 20 °C for 2 months. The species composition of diatoms was determined in constant preparations on the Elyashev's medium using fouling glasses calcinated on a copper plate for 1.5 h.
The ecological characteristics of indicator species were taken from [11], and life forms (ecobiomorphs) of soil cyanobacteria and algae were described according to the monograph by Shtina and Gollerbakh [12]. The life forms of microphototrophs are the ecological groups with similar adaptations to life in soil. The main characteristics of them are described below.

C, H, X-life forms are shade-tolerant and hygrophilous, but differ in their adaptations to the soil desiccation. C-form is represented by algae and cyanobacteria that react to the decrease in soil moisture content by the formation of abundant mucus, having a high water retention capacity. X-form is represented by unicellular algae that avoid low soil moisture by living inside soil and capable of both photosynthesis and the use of organic carbon. H-form is filamentous algae, scattered among soil particles or forming deposits on the soil surface under the protection of higher plants. M- and P-forms include filamentous cyanobacteria-xerophytes, which possess a cell protoplast resistant to low soil moisture, the M-form also has hydrophilic coatings. B-form is represented by diatoms: cold-resistant, light-loving, many of them are halophilic. Ch-form is unicellular and colonial green and partly ochrophyte algae with exceptionally high resistance to a variety of extreme environmental conditions due to the features of the protoplast and the ability to heterotrophic nutrition.

The composition of the life forms of microphototrophs allows us to identify such directions of anthropogenic soil transformation as xerophytization and surface insolation.

The following biological parameters were analyzed: the algae and cyanobacteria species composition and life forms; ecological groups of diatoms-indicators of alkaline-acidic conditions and salts content ratio; dominant species number, species in one sample average number.

Chemical Analysis of Soils. The soils on the same sites were investigated at the Ecological-Geochemical Center of the Faculty of Geography, Moscow State University. In the soil samples, the following physicochemical parameters were measured [4]: pH_{water} and TDS in the water extract (soil:solution ratio 1:5) by potentiometry on a HANNA 2/3 instrument (the Netherlands); the anionic and cationic composition of water extract on a Staier ion chromatograph (Russia). The content of HMs mobile forms extracted with 1 N ammonium acetate buffer solution with EDTA (pH 4.8; soil:solution ratio 1:10) was measured by atomic absorption spectroscopy on a novAA-400 spectrometer (Analytik-Jena AG, Germany) with flame ionization and an AA-240Z atomic absorption spectrometer (Varian, USA) with electrothermal atomization. Detailed analysis of the soil properties was published earlier [4, 13].

Data Analysis. To assess the intensity of accumulation of mobile forms of HMs in the urban soils, the concentration coefficient Kc [14] was calculated according to Eq. (1):

$$Kc = C/Cb, \tag{1}$$

where C is the average concentration of the mobile forms of the element in the studied soils, and Cb is the average concentration of the mobile forms of the element in the soddy-podzolic soils of the background site under natural forest vegetation.

To evaluate the ecological risk of soil pollution with mobile forms of HMS, the environmental hazard coefficient Ko was counted up according to Eq. (2):

$$Ko = C/MPC, \tag{2}$$

where C is the average concentration of the mobile forms of the element in the studied soils, and MPC is the maximum permissible concentration for the mobile forms of the element in soils. In Russia MPCs of HMs mobile forms in the soil are (mg/kg): Cu, 3.0;

Zn, 23.0; Pb, 6.0 [15]. For the mobile forms of cadmium in soils MPC has not been established.

Quantitative data were processed using software Statistics 8.

3 Results and Discussion

3.1 Physicochemical Properties of Soils

Soils of the Background Site. Background soddy-podzolic soils under forest communities have a slightly acid reaction, and those under sown meadow have a neutral reaction due to the liming. They are not saline; Ca^{2+} and HCO_3^- predominate among ions in the water extracts (Table 1). Liming and fertilizer application does not cause the contamination of cultivated soddy-podzolic soils. Most of the determined heavy metals are in lower concentrations as compared with their average abundances in the lithosphere [13]. The Cu and Zn mobile forms content in background soils is significantly below the MPC, at the same time the Pb level exceeds MPC twice. This excess can be apparently explained by the aerial lead addition from roads and by its mobile forms formation in acidic forest soddy-podzolic soils.

Table 1. Physicochemical soils properties in the background site and in different Moscow land-use zones (from [4, 13])[a]

Parameters	Background site		Recreational zone (park, n = 3)	Residential zone (n = 10)	Traffic zone (n = 15)
	Forest (n = 5)	Meadow (n = 3)			
pH_{H2O}	$\frac{6.2}{6.0–6.5}$	$\frac{6.7}{6.5–6.9}$	$\frac{6.4}{6.4-6.5}$	$\frac{6.9}{6.6–7.5}$	$\frac{7.0}{6.3–7.7}$
Salts, %	$\frac{0.05}{0.04–0.07}$	$\frac{0.06}{0.05–0.08}$	$\frac{0.05}{0.04–0.07}$	$\frac{0.10}{0.04–0.20}$	$\frac{0.11}{0.03–0.23}$
Ionic composition of water extracts	HCO_3-Ca	NO_3-HCO_3-Ca	HCO_3-Na-Ca, Cl-HCO_3-Ca-Na	HCO_3-Na-Ca, Cl-HCO_3-Ca-Na, NO_3-HCO_3-Na-Ca	Cl-HCO_3-Ca-Na, Cl-NO_3-HCO_3-Na-Ca, Cl-HCO_3-NO_3-Ca-Na
Kc for mobile forms:					
Cu	1.0	0.8	5.4	8.8	4.6
Zn	1.0	0.3	1.7	3.0	4.7
Cd	1.0	1.1	1.9	5.1	1.7
Pb	1.0	0.4	0.9	0.7	1.2

[a]Numerator—average; denominator—maximum and minimum values.

Urban Soils. Anthropogenic impact on soils includes mechanical changes (mechanical impact) and chemicals additional supply (geochemical impact). In addition, in the city the spot illumination and the soil moisture content may influence the development of soil microorganisms. The background cultivated soddy-podzolic soils and the urban soils differ by the type and the intensity of anthropogenic impact. According to these criteria, different city land-use zones are identified (Table 2). Geochemical impact on urban soils leads to their alkalinization, additional input of sodium and calcium chloride and nitrate with deicing reagents (DRs), and to contamination with HMs (where Zn, Cu, Cd, Pb predominate) – Table 1.

Table 2. Main types of anthropogenic impact on cultivated background soils and on different Moscow land-use zones soils

Impact type	Background site, meadow (n = 3)	Moscow land-use zones		
		Recreational (park, n = 3)	Residential (n = 10)	Traffic (n = 15)
Mechanical	Plowing	Compaction as a result of soil trampling		
			Fertile ground periodic addition	
Geochemical	Lime and fertilizers addition	Pollutants, marble debris, deicing reagents addition		
Change in surface insolation	Insolation increasing as a result of plowing and grass mowing in the fall	Insolation increasing as a result of lawns mowing and projective cover decreasing due to soil trampling		
			Buildings shading	

Urban soils are characterized by high spatial heterogeneity of all physical and chemical parameters. Specifically, in the recreational zone (in the park), the soils have a slightly acid reaction, in the residential and traffic zones, neutral soils predominate, and in some parts of the lawns near the roads soils with slightly alkaline reaction are found.

According to the salt content in the upper horizon (estimated on the basis of the insoluble residue), urban soils are classified as non-saline (<0.1% salts), slightly saline (0.1–0.2% salts) and in some cases as moderately saline (0.2–0.4%) [16].

In urban soils, the levels of HMs accumulation are also different (Table 1). At the same time, in all land-use zones the contents of all studied HMs mobile forms reach levels, dangerous for urban ecosystems. Ranked according to the environmental hazard coefficient *Ko*, the elements are presented in the following order: $Cu_{2.2}Pb_{1.8}$ in the recreation zone, $Cu_{3.5}Pb_{1.5}$ in the residential zone and $Pb_{2.5}Zn_{2.1}Cu_{1.8}$ in the traffic zone.

The spatial heterogeneity of the studied urban soils parameters is partly caused by the upper soil horizons replacement with unpolluted fertile ground. In the same administrative district this replacement is occurring with different frequency.

3.2 Algal-Cyanobacterial Communities

Algal-Cyanobacterial Communities of the Background Site. In the background soils the vegetation type determines the algae and cyanobacteria composition. In the background forest soddy-podzolic soils the algal-cyanobacterial communities typical for taiga zone forest soils are developing. Green and streptophyte algae definitely predominate; the ochrophyte algae are quite diverse, while the diatom algae and cyanobacteria are represented by small number of species (Table 3). Organic matter and heterotrophic microorganisms abundance in the forest litter horizon suppress diatom algae and cyanobacteria growth. As a result, there is a low number of species in one sample. The algae species, shade-tolerant but non-resistant to soil desiccation (the C-, X- and H- life forms), predominate (Table 4).

Table 3. The algal-cyanobacterial communities composition in the background site soils and in different Moscow land-use zones soils[a]

Parameters	Background site		Recreational zone (n = 3)	Residential zone (n = 10)	Traffic zone (n = 15)
	Forest (n = 5)	Meadow (n = 3)			
Cyanobacteria	3 / 8.1	16 / 32.7	1 / 3.3	9 / 12.3	22 / 21.8
Algae:					
Chlorophyta + Streptophyta	22 / 59.5	20 / 40.8	12 / 40.0	28 / 38.4	40 / 39.6
Ochrophyta	10 / 27.0	5 / 10.2	9 / 30.0	13 / 17.8	12 / 11.9
Bacillariophyta	2 / 5.4	8 / 16.3	8 / 26.7	23 / 31.5	27 / 26.7
Total number species	37 / 100.0	49 / 100.0	30 / 100.0	73 / 100.0	101 / 100.0
Species number in one sample	7	16	10	7	7
Dominant species number	11	10	8	4	2–9

[a]Numerator—number of species; denominator—their percentage of the algae and cyanobacteria species total number.

In cultivated soddy-podzolic soils, annually plowed and periodically limed, under sown meadows the typical for arable soils algal-cyanobacterial communities are formed. The leading groups are cyanobacteria, green and streptophyte algae, besides, the role of diatom algae is considerable (Table 3). The number of species in one sample increases in comparison with the one in forest soddy-podzolic soils. The most diverse species of cyanobacteria are the ones that prefer no grass cover sites (the P- life form). As for the diatoms, the alkaliphilic species number reaches 40% due to periodic lime addition to soil; halophilic species are absent.

The algal-cyanobacterial communities of background site uncontaminated soils are characterized by the multispecies complex of dominant species (Table 3).

In the soils of the traffic zone the increase of the amphibial and hydrophilic algal species diversity is observed. This fact is explained by their additions into soils during daily roadway watering in the summer-autumn period.

Table 4. Algae and cyanobacteria life forms in the background site soils and in different Moscow land-use zones soils[a]

Habitats	Life forms
Background site, forest	$H_{27.7}X_{22.2}Ch_{22.2}C_{16.7}P_{2.8}B_{2.8}$Amph. + Hydr.$_{5.6}$
Background site, meadow	$P_{21.6}Ch_{17.6}H_{15.7}X_{13.7}C_{13.7}B_{11.8}M_{2.0}$Amph. + Hydr.$_{3.9}$
Moscow recreational zone, park	$Ch_{29.2}X_{25.0}H_{20.8}B_{20.8}M_{4.2}$
Moscow residential zone, lawn	$Ch_{20.3}H_{20.3}B_{18.8}X_{17.2}P_{10.9}C_{7.8}M_{1.6}$Amph. + Hydr.$_{3.1}$
Moscow traffic zone, lawn	$Ch_{20.7}H_{14.9}X_{12.6}$ $B_{12.6}C_{11.6}P_{11.5}M_{5.8}$Amph. + Hydr.$_{10.3}$

[a]Numbers indicate % of the life forms of the algae and cyanobacteria species total number.

Algal-Cyanobacterial Communities of Urban Soils. *In the recreational zone* (in the park) the algal-cyanobacterial communities of “forest” type are formed. They possess a multicomponent complex of dominant species similar to the background forest soils (Table 3). This fact means the low degree of soddy-podzolic soils anthropogenic transformation. However, due to park territory maintenance, the soil surface sun exposure is increasing, the soils alkalinization and seasonal salinization because of deicing reagents application is observed. As a consequence, considerable amount of shade-tolerant and salt-nonresistant green and streptophyte algae species (the C- and H- life forms) disappears. At the same time, the photophilous diatom algae (the B- life form) appear in algal-cyanobacterial communities. Among the diatom algae the species indifferent to high salt concentration and preferring neutral pH conditions prevail. Alkaliphilic species number reaches 25% of the total diatoms number, halophilic species constitute 20% of the diatoms number. There are also unicellular green and eustigmatophyte algae that belong to the particularly resistant in extreme conditions Ch- life form. As a result, the algal-cyanobacterial communities biodiversity is increasing (the number of species in one sample - see in the Table 3).

In the urbanozems of *residential and traffic zones* algal-cyanobacterial communities are of “meadow” type, the leading groups in them being cyanobacteria, green and streptophyte algae. Soil pollution, seasonal salinization, changes in exposure to sun and trampling are stronger than in the recreational zone and lead to the decrease of photosynthetic microorganisms biodiversity (average number of species per sample). In comparison with the algal-cyanobacterial communities of the cultivated soddy-podzolic soils of the background site with meadow grass cover, the ratios between cyanobacteria and algae in algal-cyanobacterial communities is changing (Table 3). The cyanobacteria share is decreasing, while the algae component share is increasing due to the diatom species diversity growth (the B- life form). Similar to the recreational zone, the halophilic and indifferent to high salt concentrations diatom species, which prefer neutral or alkaline conditions, prevail. Many of them are resistant to trampling. The diatoms halophilic and alkaliphilic species number is slightly higher in the soils of the traffic zone (24% and 44% respectively, compared to 20% and 36% in the residential zone) that reflects slightly high soil alkalinization and salinity degree. This fact is supported by soil chemical analysis.

The cyanobacteria species, typical for arable soils, disappear and are replaced by filamentous cyanobacteria which are extremely resistant to soil desiccation and high temperatures (the M- life form). This replacement is more frequently observed in the traffic zone soils and indicates soils strong drying. As for green and eustigmatophyte algae species, the most diverse species belong to the Ch- life form (including the halophilic ones). At the same time, many of shade-tolerant and moisture-demanding species (the C- and some H- life forms) disappear.

Investigations in the Western Administrative District (WAD) have demonstrated that, even with the same land use, the algal-cyanobacterial communities structure and basic parameters vary in space, reflecting the spatial heterogeneity of the properties of urban soils. Specifically, in the WAD transport zone, the structural changes in the microphototrophs communities are the most expressed in the soils adjacent to the Moscow ring road. The diatom algae share in these soils reaches 21.1% of the total species number, and the cyanobacteria share decreases to 15.8%. Halophilic diatom species (33.3% of their number) and the Ch-form representatives (28.5%) possess the most considerable diversity. Moreover, the minimal number of dominant species is revealed.

At the same time, the diatoms (16.0%) and cyanobacteria (28.0%) ratio in the soils adjacent to the major highways is closest to the algal-cyanobacterial communities of the uncontaminated cultivated soddy-podzolic soils; the halophilic diatom species (16.7%) and Ch-form representatives (19.1%) share is also close to the background site cultivated soils; the dominant species number is significantly high. The main reason of all these transformations is the upper soil horizon replacement with an unpolluted ground that occurs annually near the highways in WAD.

In contrast, near the Moscow Ring Road and in the WAD residential zone this replacement is more rarely observed (less often one time in five years). The algal-cyanobacterial communities composition in these soils is similar and, as a result, it is possible to make a conclusion about a similar chronic anthropogenic impact on the soils.

The influence of phytocenosis type, salts and HMs mobile forms in soils on algae and cyanobacteria species diversity was confirmed by regression analysis [17, in press].

4 Conclusion

Xerophytization, compaction, alkalinization, seasonal salinization and pollution are the main trends in anthropogenic transformations in the observed urban soils. In accordance with these transformations, the algal-cyanobacterial communities composition is also modified. Resistant species replace sensitive to anthropogenic impact, i.e. – photophilic, soil compaction and desiccation-resistant, alkaliphilic, halophilic and tolerant to high HMs level. This replacement is occurring in all land-use zones and indicates that all observed urban soils belong to the resistance zone, which is characterized by a high anthropogenic impact [18]. The observed algal-cyanobacterial communities composition indicates that the main factors affecting the algal-cyanobacterial communities parameters are vegetation type, soil pH, water-soluble salts and HMs mobile forms contents, soil surface sun exposure and soil moisture. Two trends are observed in the transformation of microphototrophs' diversity. The first one is recorded in the recreational zone forest soils (in the park) that are under a relatively low mechanical and geochemical impact. As a result, the algae and cyanobacteria diversity increases in comparison with background forest site soils. The second trend is observed in the residential and traffic land-use zones soils covered with a lawn: the algae and cyanobacteria biodiversity decreases and the species number in one sample decreases more than two times in comparison with background soils biodiversity. This fact means a considerable increase of the soils anthropogenic impact level.

Algal-cyanobacterial communities are perspective for research as their parameters provide an additional data about current urban soils transformations. The important informative parameter is the ratio of indicator species with different requirements to soil moisture, spot illumination, acid-base conditions and salt content. This ratio helps to identify different technogenic processes in urban soils: waterlogging-desiccation, acidification-alkalization and salinization.

Acknowledgments. The work was supported by the Russian Geographical Society (Contract No. 03-2017/RGS-RFBR).

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