Soil microorganisms in the urban ecosystems of the russian subarctic (Murmansk region, Apatity)

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Abstract

A comprehensive study of the quantitative and qualitative parameters of soil microfungi, bacteria and algae communities in the Apatity city, located in the subarctic zone of Russia, was carried out for the first time. Urban soil samples were taken from various land-use zones (residential, recreational) and compared to arable and forest soils. In the residential zone, a decrease in the number of microfungi in the topsoil horizon to 1.1 thous. CFU/g compared to 22.7 thous. CFU/g in forest soil was revealed. In the residential zone, an increase was found in the number of saprotrophic bacteria to 7.8 million cells g^{-1} and oligotrophic to 10.9 million cells g^{-1} compared to 2.6 million cells g^{-1} and 1.8 million cells g^{-1} respectively in forest soils. In the recreational zone, the number of soil microorganisms was similar to that in the forest. A decrease in the species diversity of microfungi in the soil of the residential zone and an increase in the diversity of soil algae were revealed. Among the dominant species of fungi in urban soils, atypical species, including pathogenic ones for humans (*Penicillium dierckxii*, *Stachybotris echinatus, Fusarium sp.*), were found. In the algal community, diatoms, yellow-green algae, and cyanobacteria appeared in urban soils in comparison with forest soil. As a result of changes in the quantitative and qualitative indicators of soil microbial communities, a decrease in the enzymatic activity of soils has been noted. This may indicate a weakening of the ecosystem functions of urban soils and an increase in the degree of toxicity for living organisms and humans.

Key words: microfungi, bacteria, algae, biodiversity, enzymatic activity

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Introduction

An increase in anthropogenic load and the incidence of the population in recent years has led to increased attention to the study of the urban agglomeration's ecolo-

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gy (Morel et al. 2015, Schmidt 2016, Hui et al. 2017, Huot et al. 2017, Steffan et al. 2018, Vasenev and Kuzyakov 2018). Urbanization has a significant impact on the environment and leads to irreversible changes in the relief, hydrological conditions, vegetation, and soils. The biological properties of urban soils can serve as indicators of their ecosystem functions (Shtina and Gollerbakh 1976, Artamonova 2002, Trukhnitskaya and Chizhevskaya 2008, Sharkova et al. 2011, Gupta et al. 2017, Ivashchenko et al. 2019). The most significant biological characteristics of urban soils are microbial diversity and activity (Schindelbeck et al. 2008, Rozanova et al. 2016). Proportion of various ecological and trophic groups of microorganisms and enzymatic activity of soils are important indicators that directly depend on the characteristics of the microbial community (Schmidt 2016). The evaluation of microorganisms occupying an opposite position in trophic chains (phototrophic - algae and cyanobacteria, and heterotrophic microorganisms - bacteria and microfungi) is also important. It most adequately reflects the ongoing microbiological processes in the soil, characterizing its production and destructive potential (Domracheva et al. 2006).

Recently, the methods of molecular genetic analysis have been widely used in the studies of soil microbial communities. However, they do not allow to assess the relative abundance of species (taxa) within rather homogeneous groups of microorganisms with subsequent differentiating accounts of colonies and characteristics of the community structure. In this respect, the traditional methods of culturable microorganisms have not lost their relevance at present, even though no more than 1% of microorganisms living in natural biotopes are able to grow on nutrient media. Recent plating methods make it possible to evaluate the physiological, biochemical, and morphological characteristics of microorganisms. Therefore, preliminary taxonomic identification can be conducted, as well as the biomass accumulation of certain strains may allow to extract complete genomes for further molecular genetic analysis.

The studies of urban soil microbial community were mainly conducted in areas with a temperate and warm climate, whereas the northern regions remained overlooked (Stepanov et al. 2005, Guilland et al. 2018). Most of the studies were carried out in the USA and China (Han et al. 2011, Reese et al. 2016, Yan et al. 2016, Gill et al. 2017, Wang et al. 2017), Morocco and Poland (Naylo et al. 2019, Beroigui et al. 2020). A similar study was conducted in Finland (Hui et al. 2017). On the Kola Peninsula, soil microorganisms of urban areas were studied only in Murmansk and Kandalaksha (Marfenina et al. 2002, Peretrukhina 2011, Turchanovskaya and Bogdanova 2011). Therefore, we selected Apatity as another location for evaluation of soil microbiota. The purpose of this work is to study the quantitative and qualitative indicators of microorganisms communities (bacteria, microfungi, and algae) in the urban soils of Apatity compared to the forest soils.

Material and Methods

Climate characteristics of the research area

The Apatity (Murmansk region) is the fifth largest polar city. It is located on the Kola Peninsula beyond the Arctic Circle. The climate is continental, cold and humid (Kottek et al. 2006) with the lowest monthly average temperature (January) of -13.5°C and a record minimum temperature of -47°C observed in 1985. The maximum average monthly temperature was detected in July and changed from +10 to +18°C. The air temperature in the city is usually 1–2 degrees higher than in the background

landscapes outside of it (Demin et al. 2016), which can have a decisive impact on the soil biota. The average annual precipitation is 853 mm, with the greatest amount falling from September to December (about 100 mm in each of the months) [1]-Weather online;[2]-Climatic data 2020. The prevailing wind direction is northwest.

Characteristics of site

The research focused on urban soils in different land use zones (residential and recreational) in comparison to arable and forest soil. The forest soil is a podzol on lake-glacial deposits. The site is located 15 km from Apatity in the northern taiga zone and does not experience pressure from industrial enterprises. Site characteristics are described in Table 1. The names of the soils are given according to the World Reference Base ([3]-FAO 2015).

Site	Land use zone	Coordinates	Soil, according to WRB*	Vegetation
S-R	Social-recreational	67.56978 33.40082	Umbric Leptic Entic Podzol (Arenic, Technic)	*Betula pubescens, Salix caprea, Populus sp., Poa pratensis, Festuca rubra, F. pratensis, Lolium perenne*
RZ-O	Residential, external court yard	67.56506 33.41000	Umbric Leptic Entic Podzol (Arenic, Technic)	*Larix sibirica, Betula pubescens, Sorbus gorodkovii, Poa pratensis, Festuca rubra, Lolium perenne, Taraxacum officinale*
RZ-I	Residential, inner court yard	67.56139 33.41057	Umbric Leptic Albic Podzol (Arenic)	*Betula pubescens, Salix caprea, Poa pratensis, Festuca rubra, F.pratensis, Lolium perenne*
AR	Agricultural	67.57959 33.30014	Plaggic Entic Podzol (Arenic)	absent
RZ-I-TR	Residential, inner court yard, pedestrian road (without a hard surface)	67.56139 33.41057	Umbric Leptic Albic Podzol (Arenic)	absent
RZ-I-PG	Residential, inner court yard, playground (sandy)	67.56139 33.41057	Umbric Leptic Albic Podzol (Arenic, Technic)	absent
FT	Forest (background)	67.57885 33.29762	Folic Leptic Albic Podzol (Arenic)	*Pinus friesiana, Picea obovata, Betula pubescens, Juniperus sp., Vaccinium vitis-idaea, V. myrtillus, Equisetum arvense*

Table 1. Characteristics of research areas. *Note*: * WRB - World Reference Base.

Sampling

The soil samples were collected from a depth of 0-10 cm in five replicates in the second decade of June 2019 by the «envelope» method. Culturable microfungi were identified in fresh samples the day after collection.

Enzymatic activity of soil

The activity of the hydrolytic enzyme (invertase) and redox enzyme (dehydrogenase) was studied. The invertase activity was determined colorimetrically using the method of Hoffman and Pallauf. The method is based on the ability of glucose and fructose, formed during the hydrolysis of sucrose, to reduce CuO to Cu_2O (Hoffman and Pallauf 1965, Mineyev et al. 2001). Dehydrogenase activity was determined by a colorimetric method based on the reduction of the colorless salt of 2,3,5-triphenyltetrazolium chloride to a red color triphenylformazan (Galstyan 1974, Mineyev et al. 2001).

Microscopic fungi

The number of colony-forming units (CFU) and the diversity of culturable microfungi were determined by plating methods on Czapek's medium with lactic acid (4 ml/l) to inhibit bacteria growth (Zvyagintsev 1991). Incubation took place in thermostat at the temperature of +27°C for 7 – 10 days and at +5°C for 5–6 weeks to isolate psychrotolerant strains. The observation of the microfungal diversity was performed based on cultural and morphological features (Olympus CX41 microscope) using keys (Klich 2002, Domsch et al. 2007, Seifert et al. 2011). The species name and systematic position are given according to the database: CABI Bioscience Databases ([4]-Index Fungorum 2021). For the sterile mycelium, identification was performed by the analysis of the ITS1–5.8 S–ITS2 rDNA region. The DNA was isolated according to the method described by Glushakova et al. (2011). The DNA sections were sequenced using a set of BigDye TerminatorV reagents 3.1 Cycle Sequencing Kit(Applied Biosystems, USA) with subsequent analysis of reaction products on the Applied Biosystems 3130l Genetic Analyzer sequencer at the Syntol Research and Production Center (Moscow).

Bacteria

The saprotrophic bacteria number was determined by plating method on meat-peptone agar, the oligotrophic bacteria number, on the low-mineralized Aristovskaya medium (Hoult et al. 1997). Incubation took place in thermostat at the temperature of +27°C for 3–5 days. Bacteria were identified as a genus based on morphological and cultural characteristics.

Soil algae and cyanobacteria

The soil suspension was sown on liquid and agarized nutrient media 3N-BBM and Z8 (Kotai 1972, Gaysina et al. 2008). Algae cultivation took place in light installations equipped with full spectrum phyto-lamps (light intensity of 60 μmol m^{-2} s^{-1}) at a ratio of light/dark periods of 16/8h at room temperature. Identification of species was carried out in accumulative and pure cultures obtained by isolation using glass

capillaries. For the species identification, the conventional keys were used (Andreeva 1998, Ettl and Gärtner 2014, Škaloud et al. 2018). Taxon names were given according to Algaebase ([5]-AlgaeBase 2021).

Statistical analysis

Mathematical processing of the results was done using standard software packages for statistical calculations (Microsoft Office Excel 2016 and Statistica). The significance of the differences between the samples (t) was evaluated using the Student's test; the correlation coefficient (r) was calculated by the square method (Pearson's method) for the significance level of 0.05.

Results and Discussion

The number of microfungi and bacteria

It is known that urban soils differ in properties from forest soils and this affects microorganisms (Marfenina et al. 2002, Ivanova et al. 2015, Marfenina and Danilogorskaya 2017). The number of microfungi in the topsoil horizons of the urban soils ranged from 1×10^3 to 9×10^4 CFU/g (Table 2). The minimum number was found in the soil of the court yard (RZ-I) and on the pedestrian road in the same court yard (RZ-I-TR), where the soil was maximally compacted. The maximum values were found for the S-R zone soils. The number of microfungi in the forest soil was 2.3×10^4 CFU/g, which is lower than for the S-R zone, apparently because of the lack of anthropogenic substrates suitable for microfungi uncharacteristic for this forest soil (Marfenina et al. 2002). In general, the forest soils of the northern taiga zone of the Kola Peninsula are characterized by a large number of microfungi, as evidenced by long-term studies (Evdokimova and Mozgova 2001, Korneikova 2018, Korneikova et al. 2018).

Some general trends in the number of culturable microfungi over the urban soil horizons were revealed. In the forest soil, CFU decreased more than 10 times from the topsoil horizon to the subsoil E horizon and then slightly increased to the subsoil Bs horizon. This trend was found earlier for the distribution of microfungi in the profile of the forest soil (Evdokimova and Mozgova 2001, Korneikova 2018) and is also characteristic of a number of physical and chemical soil properties, which is due to the leaching regime of soils (Zaydelman 2016). In the soil of RZ zone, the maximum number of microfungi was observed in subsoil Bs horizon (RZ-O) and E horizon (RZ-I) which may be due to insufficient oxygen for microfungi resulting from the compaction of the topsoil horizons during trampling (Sherman et al. 2019). In addition, the urban subsoil horizons may contain organic artifacts (Vasenev and Kuzyakov 2018), which are an additional substrate for microorganisms. In arable soil (AR), the largest number of microfungi (4.88×10^3 CFU/g) was observed in the topsoil horizon and then significantly (more than 10 times) decreased in profile. This is probably due to the most active involvement of the topsoil arable horizon in agricultural practices (fertilization, loosening, plowing) and, as a result, numerous breaks in the fungal mycelium by tillage tools, fragments of which give rise to colonies on nutrient media (Trzciński et al. 2018). In the S-R zone soil, a gradual decrease in the number of microfungi was observed in the profile in following order: organic (O) > elluvial (E) > illuvial (Bs).

This distribution is classical and has been reported by *e.g.* Polyanskaya and Zvyagintsev (2005), and Vermeire et al. (2019).

The saprotrophic and oligotrophic bacteria number of the urban topsoil horizon exceeded the microorganism's numbers of these trophic groups in the forest soil. The maximum number of heterotrophic bacteria was found in RZ-I-TR soil: 11 million cells g^{-1} of soil (Fig. 1). The bacteria number in the topsoil horizons of the RZ-I, RZ-O, and S-R zones ranged from 1.2 million to 6.7 million cells g^{-1}. In the forest soils, the number of heterotrophic bacteria reached 3.6 million cells g^{-1}, which corresponds to data from earlier studies on microbiological activity in the northern taiga soils of the Kola Peninsula. The highest number of bacteria in urban soils in comparison with forest soils is probably due to younger age of bacterial community, high growth rate of bacteria and rapid "capture" of trophic resources. This is reported in the studies of anthropogenically disturbed urban soils exposed to the influence of human household activities (Artamonova 2002, Lysak 2010, Shumilova and Kuimova 2013). This is especially typical for the soil of the pedestrian road, where a large number of people and animals are present and, accordingly, the additional sources of soil nutrition. In addition, the smallest number of microfungi was found here, as a consequence of the absence of competition for food sources between fungi and bacteria.

Despite their high number, the species diversity of bacteria in all urban soil samples was rather low. Bacteria g. *Pseudomonas* and *Arthrobacter* dominated and spore bacteria of the genus *Bacillus* were less common, which confirm numerous data on the simplification of the microbial communities structure of urban soils, as well as a decrease in the number of bacilli under the influence of deterioration of the sanitary situation (Artamonova 2002).

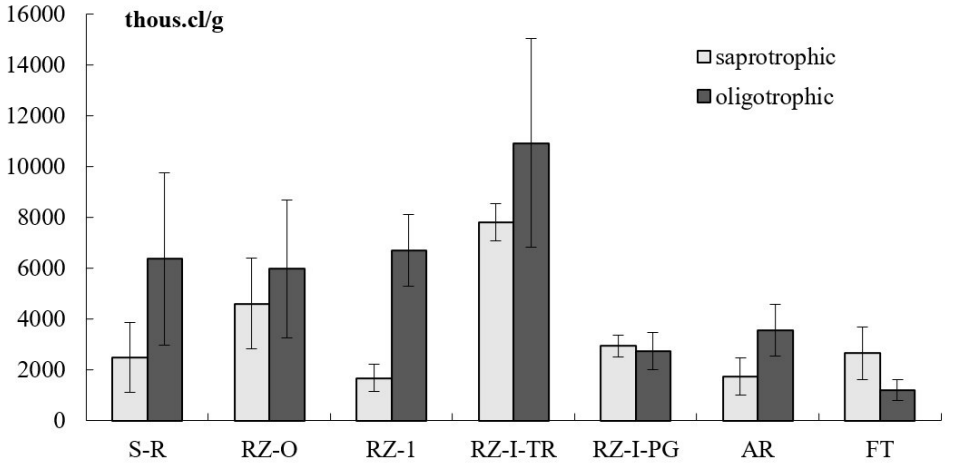

Fig. 1. Number of saprotrophic and oligotrophic bacteria in the topsoil horizon.

The number of saprotrophic and oligotrophic bacteria decreased gradually along the soil profile in both urban and forest soils. In the subsoil horizons, it was an order of magnitude lower than in the topsoil horizon (Table 2). However, for the urban subsoil horizons, the second maxima of the bacteria number were revealed (Lysak

2010). On the whole, the bacteria number varied along the soil profile from 11 thous. to 6 million cells g^{-1} of soil. In the arable soil, the number of bacteria and microfungi decreased with depth as well.

Diversity of soil microfungi

The species diversity of soil culturable microfungi was represented by 22 species belonging to 11 genera, 9 families (*Aspergillaceae, Ceratocystidaceae, Chaetomiaceae, Hypocreaceae*, *Mortierellaceae, Nectriaceae, Stachybotryaceae, Torulaceae*, *Umbelopsidaceae*) 7 orders (*Eurotiales, Hypocreales, Microascales*, *Mortierellales, Pleosporales*, *Sordariales, Umbelopsidales*) 5 classes (*Dothideomycetes, Eurotiomycetes, Mortierellomycetes, Sordariomycetes, Umbelopsidomycetes*) and 2 phyla (*Ascomycota, Mucoromycota*) (*see* Fig. 2). The *Mucoromycota* was represented by the genera *Mortierella* and *Umbelopsis*. The *Ascomycota* division was represented by 8 anamorphic genera (*Acremonium, Aspergillus, Berkeleyomyces, Fusarium, Penicillium, Stachybotrys, Torula, Trichocladium*). One type of sterile mycelium isolates of uncertain systematic position, has also been identified from complex cultivation.

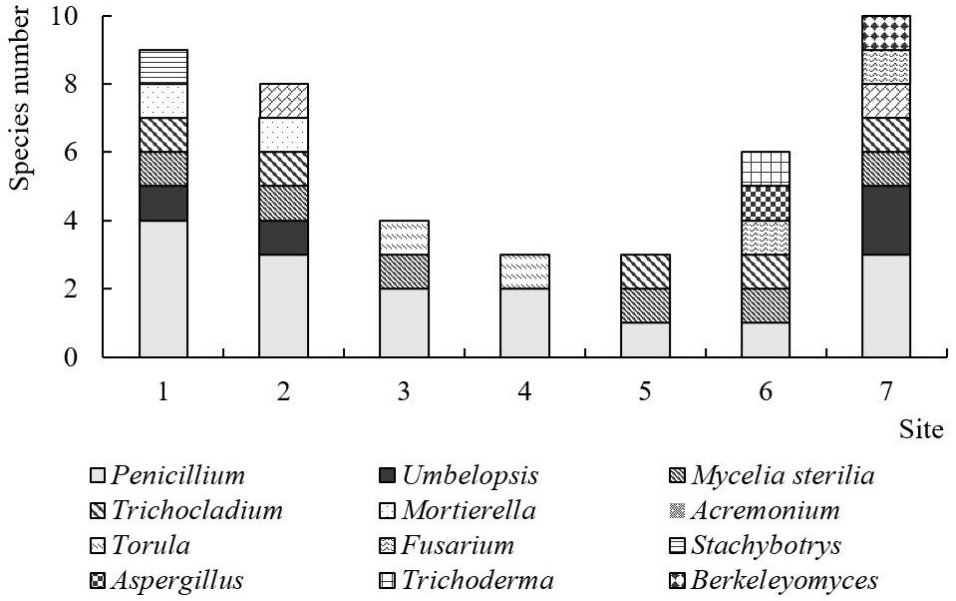

Fig. 2. Diversity of microfungi in the soils. *Note*: 1 – S-R, 2 – RZ-O, 3 – RZ-I, 4 – RZ-I-TR, 5 –RZ-I-PG, 6 – AR, 7 – FT.

The maximum number of fungal species was isolated from soils of the FT and S-R zones, which may be due to their maximum similarity to the natural biotopes (Ivanova et al. 2015). Both similarities and differences in the species composition of microscopic fungi communities for the soils were found. Thus, *Trichocladium griseum*, a typical phytopathogen and cellulolytic (Domsch et al. 2007), was isolated

from the soils of almost all the functional zones studied, except for the court yard soil. *Penicillium spinulosum* and sterile mycelium were also found in most of the studied soils, while *Acremonium felinum*, *Aspergillus fumigatus, Berkeleyomyces basicola, Penicillium aurantiogriseum, P. canescens, P. decumbens, P. dierckxii, P. nalgiovense, Trichoderma koningii* and *Stachybotrys echinatus* were isolated from only one sample under study. The genus *Penicillium* (9 species), whose representatives are typical saprotrophs, was characterized by the greatest species diversity (Domsch et al. 2007, Seifert and Gams 2011) and are often found in the forest soils of the Kola Peninsula (Evdokimova and Mozgova 2001, Marfenina et al. 2002, Korneikova 2018, Korneikova et al. 2018). In urban soils, they also dominated and accounted for 40–70% of the total number of isolated species. The exception was arable soil, where the proportion of *Penicillium* was only 16%. The species composition of the soil microfungal complexes is probably greatly influenced by the cultivated plants and their associated microfungal complexes, including pathogenic species, which is also reflected in a number of studies (Carvalhais et al. 2019, Wille et al. 2019, Ye et al. 2020).

The species composition of the urban soil fungal complexes of different land use zones differed significantly from one another, as evidenced by the low values of the Sørensen-Chekanovsky coefficient. The most similar (47%) were the soils of the S-R and FT zones. The remaining sites were characterized by a specific species composition of microfungal complexes and had a very low degree of similarity with the forest soil.

Urban soils fungal complexes in different land use zones differed in structure of dominant species. The reason for this may be the heterogeneity of urban soils and the presence of specific substrates for microfungi (Marfenina et al. 2017). Fungal community in the RZ zones soils was characterized by monodominant structure, *i.e.* it had one dominant with a high frequency of occurrence. In the RZ-I soil, the abundance of *P. dierckxii* was 82%, and in the RZ-I-PG soil, the abundance of *P. melinii* was 85%. Representatives of the genus *Penicillium* often dominate in abundance in the soils of the northern regions (Domsch et al. 2007).

Soils of FT and S-R zones were characterized by polydominant structure complexes of microscopic fungi. In the S-R zone, *Penicillium melinii, P. simplicissimum,* and *Stachybotrys echinatus* prevailed, while *P. decumbens, P. melinii*, and *Umbelopsis isabellina* predominated in the FT zone. The polydominant structure of microfungal complexes was also characteristic of arable soil. The abundance of the predominant species was 43% (*Fusarium sp.*), 29% (*Trichocladium griseum*), and 21% (*P. miczynskii*).

Comparing the composition of the dominant species in forest and urban soils, the appearance of atypical species in the city was noted. For example, the species *Trichocladium griseum* was previously found in the soils of the region but belonged to the group of random and rare species. Microfungi of the genus *Fusarium*, which dominate in arable soil, are also not characteristic of the soils of the Kola Peninsula. As is known, species of this genus are often parasites on cultivated and forage plants (Domsch et al. 2007). This probably explains their large number in arable soil. The dominance of dark-pigmented microfungi in urban soils also attracts attention. It is known that pigmentation of organisms is a protective function against negative effects (Nosanchuk et al. 2015, Marfenina et al. 2017), and at the same time, most of the melanized microfungi belong to the group of opportunistic pathogens for humans (Marfenina and Danilogorskaya 2017).

Diversity of soil algae and cyanobacteria

In the urban soils, peculiar communities of algae and cyanobacteria are formed, which differ in taxonomic composition, the complex of dominant species, ecological structure, as well as in abundance and biomass (Shtina 1990, Artamonova 2002, Sharipova and Dubovik 2004, Aksenova and Baranova 2010, Khaybullina et al. 2011, Bachura and Blagodatnova 2015, Dorokhova et al. 2015, Maltsev et al. 2017).

In the studied soils, 50 species of algae and cyanobacteria were found belonging to 3 divisions: *Chlorophyta* (classes *Chlorophyceae, Trebouxiophyceae, Ulvophyceae*) - 36 species, *Ochrophyta* (classes *Bacillariophyceae, Xanthophyceae*) - 10 species, *Cyanobacteria* - 4 species. At the same time, there was a significant increase in the diversity of algae in urban soils (49 species versus 6 in forest soil), which is associated with the emergence of new ecological niches and is generally quite typical for places with relatively poor and fairly homogeneous floristic composition of algal groups, for example, for the taiga zone (Kabirov 1991). The difference in habitat conditions explains the low degree of similarity in the species composition of microphototrophic communities in the surveyed areas – the Sørensen-Chekanovsky coefficient does not exceed 25%. The maximum diversity was found in the soil of the S-R zone (19 species), as well as in the substrate from the pedestrian road (RZ-I-TR) (20 species). The increase in species diversity was explained by the effect of "intermediate disturbance", in which the maximum diversity is preserved at the average intensity of the impact of disturbing factors (Odum 1986, Shea et al. 2004). The smallest number of species (only 5) was found in the soil of the RZ-I zone (Fig. 3). At the same time, this site does not differ from others by the abnormal level of soil contamination. According to our assumptions, the low species diversity here is due to the strong shading of the court yard.

A change in the structure of soil algae communities in urban soils compared to forest soils was revealed. The forest was characterized by absolute dominance of green algae, including genera *Elliptochloris, Neocystis, Pseudococcomyxa, Stichococcus*, *etc*. At the same time, the predominance of algae from the division *Chlorophyta* was found. Their low diversity is often characteristic for northern podzolic soils under tundra and forest vegetation (Evdokimova and Mozgova 2001, Korneykova et. al. 2017). In the soils of the RZ zone, algae from the *Chlorophyta* division reached 74-82%, while in arable soil, on the playground and on the pedestrian road, their share decreased to 54-60%. Changes in the community's structure occur due to the appearance and growth of the diversity of diatoms, yellow-green algae (*Botrydiopsis, Xanthonema*) and cyanobacteria (Fig. 3). Previously, we found a noticeable diversity within these groups in fouling on the surface of technogenic substrates (Redkina et al. 2020, Davydov and Redkina 2021), as well as in disturbed soils near the Kandalaksha aluminum plant (Redkina et al. 2020). It should be noted that the degree of development of yellow-green algae is an indirect indicator of the soil "purity". When the substrate is heavily contaminated, representatives of this division are the first to "drop out" from the algal community (Shtina 1990). Micrographs of some algae species found in urban soils were shown in Fig. 4.

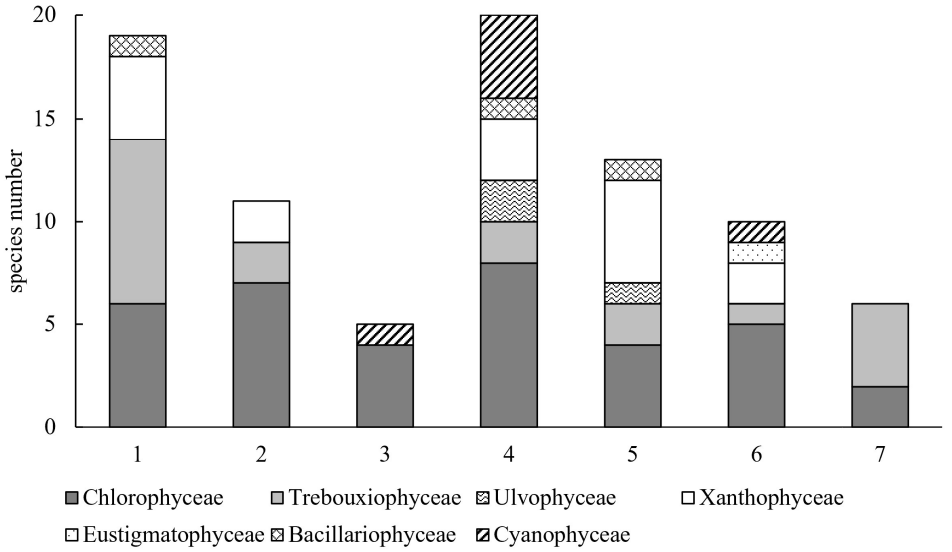

Fig. 3. Taxonomic structure of cyanobacterial and algal communities in the soils. *Note*: 1 – S-R, 2 – RZ-O, 3 – RZ-I, 4 – RZ-I-TR, 5 –RZ-I-PG, 6 – AR, 7 – FT.

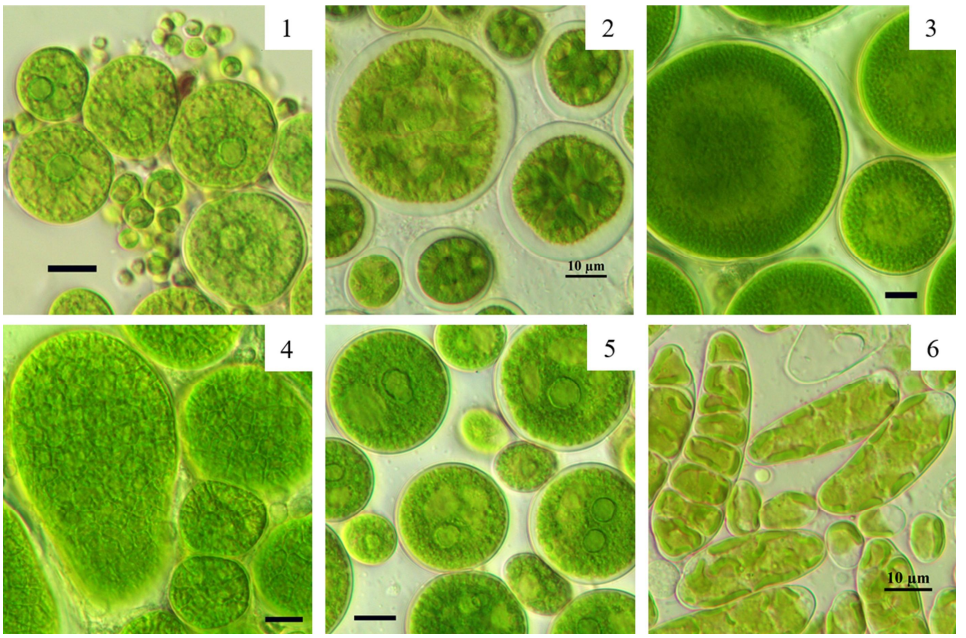

Fig. 4. Micrographs of some algae species. 1 – *Neospongiococcum* cf. *commatiforme*, 2 – *Actinochloristerrestris*, 3 – *Pseudodictyochlorisdissecta*, 4 – *Dictyococcusvarians*, 5 – *Macrochlorismultinucleate*, 6 – *Bumilleriopsisfiliformis*.

Enzymatic activity of soil

The enzymatic activity is one of the indicators of the soil's biological activity, which characterizes the processes taking place in it. The study of invertase activity is of great interest because this enzyme is involved in carbohydrate metabolism in the soil, carrying out the hydrolytic degradation of incoming organic matter in the process of humus formation. Dehydrogenases catalyze the dehydrogenation reactions of organic substances (carbohydrates, organic acids, alcohols, humic acids, *etc*.) and act as intermediate hydrogen carriers. In the soil, dehydrogenases of carbohydrates and organic acids are active. Dehydrogenase activity is an indicator of the vital activity of microorganisms and the amount of degradable humic substances.

Decrease in the enzymatic activity in the urban topsoil horizons was apparent in comparison with the FT soils (Table 2). This trend was also reported for the more southern regions: the urbanized territories of Azerbaijan (Kazimov and Ali 2012), Rostov-on-Don, and Azov (Baranova et al. 2010). However, in the soil of the court yard (R-Z), the invertase activity was comparable to that in the FT soil, while the dehydrogenase activity was higher. The enzyme activity in the soil of the S-R zone is 2.5 times lower than in the FT zone, but at the same time, it is 2 times higher than in the AR zone. Some data show that the enzymatic activity of soils in S-R areas is close to that in natural soils (Zabelina 2014). It may indicate a significant potential for soil self-purification as shown by Trifonova and Zabelina (2017). The minimum value of enzymatic activity was found in AR soil, probably due to a low input of organic carbon with plant litter, a low number of microorganisms, and the lowest pH value of all the studied soils.

The highest activity of the studied enzymes was observed on the pedestrian road. In the same sample, the maximum number of bacteria was observed. This is probably due to the increased load from pedestrian and animal foot traffic, *etc*. From an ecological perspective, these results can be considered an adaptive response of the soil to anthropogenic loads, neutralization of pollution and self-cleaning of the soil (Trifonova and Zabelina 2017).

It is known that enzymes enter the soil because of the activity of microorganisms, with root secretions, from decaying animal and plant remain (Mishustin and Shilnikova 1968, Khaziyev 1972, 1976). In different urban functional zones, different groups of microorganisms can have a decisive influence on the enzymatic activity. In the S-R, AR, and FT zones, a strong positive correlation ($r = 0.97 - 1.00$) was established between the activity of enzymes and the number of microorganisms in both groups (bacteria and microfungi), whereas in the soil of the RZ zone, the activity of enzymes demonstrates the greatest correlation with the number of bacteria ($r = 0.96 - 0.99$).

Enzymatic activity in urban and forest soils decreased along the soil profile from the topsoil horizons to the lower. In FT soils, the distribution of enzymes along the soil profile corresponded to the distribution of the microorganisms: a decrease in activity in the subsoil E horizon, then a slight increase in the subsoil Bs horizon. The same trend was found for the soil of the court yard of the RZ zone. In this case, the vertical distribution of enzyme activity was due to the structure of the soil profile: there was an E horizon, where organic matter accumulates. In the soils of the other functional zones, the enzyme activity decreased evenly down the soil profile.

Soil pit	Depth, cm	Number of microorganisms			Invertase activity, mg gluc/g soil in 18 h	Dehydrogenase activity, mg TPF/10g soil in 24 h
		microfungi, thous. CFU/g	bacteria, thous. cells/g			
			saprotrophic	oligotrophic		
S-R Umbric Leptic Entic Podzol (Arenic, Technic)						
Aur	0-12 (16)	89.2±21.9	2480±1374	6378±3387	11.62±1.39	1.08±0.13
Bu	12(16)-29(31)	-	-	-	-	-
E	29(31)-31(34)	19.4±2.9	322±154	415±275	0.81±0.08	0.27±0.03
Bs	31(34)-45	0.7±0.3	151±36	88±18	0.59±0.07	0.19±0.02
BCg	45-(55)	0.08±0.04	240±74	601±236	0.15±0.02	0.06±0.01
RZ-O Umbric Leptic Entic Podzol (Arenic, Technic)						
Au	0-15	3.13±0.59	4603±1788	5975±2725	7.94±0.95	1.08±0.13
Bu	15-27	2.07±0.18	187±51	404±115	1.10±0.01	0.27±0.03
Bs	27-35	8.73±1.16	308±97	547±182	0.10±0.01	0.20±0.02
BCg	35 (55)	0.15±0.02	57±40	149±45	0.18±0.02	0.03±0.01
RZ-I Umbric Leptic Albic Podzol (Arenic)						
Au	0-5	1.64±0.84	1680±536	6703±1399	27.49±3.30	2.31±0.28
E	5-10	3.68±0.08	483±230	820±306	3.38±0.41	0.34±0.04
Bs	10-15	0.47±0.09	39±80	985±185	5.51±0.66	0.42±0.05
Bs	20-25	0	65±20	127±27	0.29±0.03	0.16±0.02
BCg	30-35	0.2±0.00	51±23	131±37	0.44±0.05	0.04±0.01
RZ-I-TR Umbric Leptic Albic Podzol (Arenic)						
Au,d	0-5	1.11±0.9	7825±737	10927±4105	137.92±16.55	2.51±0.30

RZ-I-PG Umbric Leptic Albic Podzol (Arenic, Technic)						
TCH	0-5	3.9±0.2	2940±441	2738±742	15.59±1.87	0.82±0.10
AR Plaggic Entic Podzol (Arenic)						
Ap	0-5	4.88±0.88	1740±718	3563±1015	1.98±0.24	0.58±0.07
Bs	20-25	0.49±0.09	348±80	1126±392	0.22±0.03	0.17±0.02
BCg	30-35	0.35±0.05	103±37	60±19	0.15±0.02	0.10±0.01
C	45-50	0	6±1	9±3	0.07±0.01	0.03±0.01
FT Folic Leptic Albic Podzol (Arenic)						
O	0-5	22.7±4.3	2654±1049	1803±81	27.94±3.35	1.90±0.23
E	7-10	1.46±0.43	354±114	650±229	1.18±0.14	0.23±0.03
Bs	15-20	6.82±0.62	347±97	1027±620	1.54±0.18	0.27±0.03
BC	40-45	0.01±0	341±81	751±227	0.33±0.04	0.03±0.01

Note: - - not analyzed

Table 2. Number of soil microorganisms and soil enzymatic activity.

Conclusion

Significant differences in the quantitative and qualitative parameters of the culturable microorganism's communities (bacteria, microfungi, algae) in urban soils in the subarctic zone compared with the forest soils were revealed. According to the indicators used in this study (number of microfungi, bacteria, soil enzymatic activity, species diversity of microfungi and algae), the soil microorganisms communities in the S-R zone were the most similar to FT zone, which may be due to a lower level of anthropogenic load on this territory. Soils of RZ zones revealed a marked decrease in the fungi number, with some growth in the oligotrophic bacteria number; the decrease of enzymatic activity was observed only in the soil of the RZ-O, near the road. In the substrate of a pedestrian road without a hard surface, a sharp increase in the heterotrophic bacteria number and a growth in the enzymatic activity, especially invertase, were recorded with a significant decrease in the microfungi number. The algae and cyanobacteria communities in this area were characterized by maximum diversity. The increased load on this site from humans and animals probably contributes significantly to the state of the microbial communities (Sherman et al. 2019).

Some trends in the microorganism's distribution in the soil profile were revealed. In the urban soils of the RZ zone, the greatest number of fungi was found in the subsoil horizons, while in the FT - in the topsoil horizon. The bacteria number was always highest in the topsoil horizons and decreased quite evenly down the profile.

In total, 22 species of microscopic fungi and 50 species of soil algae were found in the urban soils. There was a decrease in the diversity of culturable microfungi and bacteria with an increase in the microalgae diversity in urban soils compared with FT soils. In urban areas, the dominance type of microfungal communities' changes to monodominant, whereas FT soil was characterized by a polydominant structure. In the composition of microalgae, the appearance of groups atypical for the background soils of the region was witnessed: diatoms, yellow-green algae, and cyanobacteria.

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