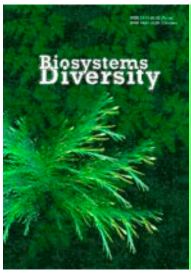


Biosystems Diversity

ISSN 2519-8513 (Print)
ISSN 2520-2529 (Online)
Biosyst. Divers., 25(4), 257–262
doi: 10.15421/011739

# Use of soil biota in the assessment of the ecological potential of urban soils

Y. I. Maltsev, I. A. Maltseva, A. N. Solonenko, A. G. Bren

*Bogdan Khmelnitskiy Melitopol State Pedagogical University, Melitopol, Ukraine*

*Article info*

*Received 15.10.2017*
*Received in revised form 27.11.2017*
*Accepted 30.11.2017*

*Bogdan Khmelnitskiy Melitopol State Pedagogical University, Getmanska st., 20, Melitopol, 72312, Ukraine.*
*Tel.: +38-096-548-34-36*
*E-mail: mz_5@ukr.net*

***Maltsev, Y. I., Maltseva, I. A., Solonenko, A. N., & Bren, A. G. (2017). Use of soil biota in the assessment of the ecological potential of urban soils. Biosystems Diversity, 25(4), 257–262. doi:10.15421/011739***

In assessing the ecological conditions and classification of urban soils, data about soil biota should be taken into account. The environment of urban territories is characterized by significant changes compared to their surrounding environments. It is established that the algal flora of urban soils lose their zonal features and features associated with the edification influence of higher plants. Specific biotopes with a definite species structure are formed in urboecosystems. Fifty 50 algae species have been recorded in the soils of the Henichesk urboecosystems (Kherson region, Ukraine): Cyanoprocaryota – 21, Chlorophyta – 13, Charophyta – 2, Eustigmatophyta – 1, Xanthophyta – 11, Bacillariophyta – 2. Among dominant and subdominant species were Cyanoprocaryota and Chlorophyta. The other phyla were represented by *Klebsormidium dissectum*, *K. flaccidum*, *Hantzschia amphioxys*, *Eustigmatos magnus*, *Botrydiopsis eriensis*. Compared with the surrounding environment, the urbanized flora of Henichesk has a low species richness, and is characterized by prevalence of Cyanoprocaryota and Chlorophyta species. The coefficient that takes into account the percentage of preservation of species richness in a particular urban area compared to the background indicators of species richness can be used to evaluate the urban transformation of soil biota. The degree of degradatory changes in the composition of living organisms and the direction of these changes depends on the specificity and intensity of exploitation of the territory of the urban ecosystem. The most diverse composition of algae species within the the city of Henichesk was noted in the recreational, residential, and transport zones, in comparison with the industrial zone and the zone of special use. Different functional areas of the city are distinguished not only by the algae species richness, but also by the composition of dominants. Among the dominants and subdominants of the recreational and transport zones were species of different phyla. The dominants and subdominants of the residential and industrial zones were Cyanoprocaryota species, in the zone of special use – representatives of Chlorophyta. The distribution of species richness of algae along the soil profile in the city acquires an atypical character. The species richness increases not in the most superficial layers of soil, but in the lower, aphotic parts of the soil profile. The soil biota, on the one hand, depends on the ecological conditions of soil, and on the other as a result of its life activity, changes the ecological functions of the soil, strengthening or weakening them. The reduction in the species richness of the soil algae of the urboecosystem Henichesk shows the limitations of ecological functions of urban soils. It is established that changes in the composition of algae in soils of urban ecosystems are one of the indicators of the presence and severity of transformation processes. These processes occur with the soil biota and soil as a whole under the conditions of urban ecosystems and can be used as indicators in the environmental assessment of urban soils, in the development and subsequent examination of ways to reduce negative expression of urbanization.

*Keywords*: algae; soil; urban ecosystem; biological diversity

## Introduction

Urbanization is one of the most characteristic signs of scientific and technological progress, which is associated with the rapid growth of cities and urban populations. It leads to irreversible processes of transformation of the natural environment. The consequences of urbanization are determined not only by the volume of technogenic emissions from industry and vehicles, but also by the specifics of the natural conditions of the region (droughts, high temperature, relief, etc.), which can aggravate the negative effects of anthropogenic factors (Shekhovtseva et al., 2015).

Soil is an important component of the functioning of urban ecosystems. It ensures not only terrestrial biodiversity, but is also the habitat of a large number of organisms. At the same time, the soil suffers the most powerful impact from urbanization due to the disruption of its structure, compaction, accumulation of various chemical compounds and heavy metals, changes in humus content, pH, etc. Transformation processes in city soils are various in nature and depend on their functional use. Changes in the physical and chemical properties of urban soils have a pronounced effect on their biological activity, which in turn depends on the composition and quantity of soil organisms (Shekhovtseva et al., 2015). The elucidation of the nature of the relationship between the changed soil parameters as a result of urbanization and the soil biota is necessary for assessing the ecological potential of soils in urban ecosystems and for the environmental management of urban areas (Aksoy et al., 2017). Among the factors that constitute a threat to the biodiversity of soils in urban areas are land use, erosion, compaction, pollution, etc. (Li et al., 2017). In this way, urbanization has led to the creation of specific biotopes with a characteristic species composition of living organisms (Wei et al., 2017; Caruso et al., 2017; Joimel et al., 2017).

This also applies to algae, a necessary component of both terrestrial and aquatic ecosystems. In urban ecosystems, which have a high degree of contamination by toxic substances and disruption of the soil and vegetation cover, algae play an important role as primary producers, and in the processes of self-purification and support the ecological stability of ecosystems.

Current research on the eukaryotic algae and cyanoprokaryotes of urban areas proceeds in two directions. One of them is represented by studies of the colonization processes by eukaryotic algae and cyanoprokaryotes in various artificial substrates (concrete, asphalt, glass, metal) (Gaylarde et al., 2000; Crispim et al., 2003, 2004; Crispim et al., 2004; Rindi et al., 2004; Uher et al., 2005; Gaylarde et al., 2005; Häubner et al., 2006; Menendez et al., 2006; Karsten et al., 2007; Rindi, 2007; Hallmann et al., 2011). As a result, a certain amount of information has been accumulated about their diversity, their proximity to various urban habitats, the ecology of the most widespread algal complexes (Rindi, 2007). The second direction is connected with the study of eukaryotic algae and cyanoprokaryotes of soils in urban areas.

The problem of soil algae diversity and ecology of urban areas has been raised in the works of various scientists outside Ukraine (Kabirov et al., 1997; Suhanova et al., 2000; Sharipova et al., 2004; Rahmatullina et al., 2009; Aksenova et al., 2010; Shekhovtseva et al., 2010; Suhanova et al., 2011; Truhnitskaya et al., 2012; Dorokhova et al., 2015; Bachura et al., 2015; Antipina, 2016). This has helped to reveal the certain regularities of urban soils and to outline the approaches for using them with a bioindicatory purpose. The search for bioindicators which make it possible to simultaneously assess a whole complex of ecologically significant factors in urban conditions, is being conducted by scientists among different groups of organisms (Meuser, 2010; Stankovic et al., 2013; Bessolitsyna et al., 2013; Gorovtsov et al., 2017).

The earliest data about soil algal flora of urbanized territories in Ukraine was presented in the work of Gorovits-Vlasova (1927), the purpose of this investigation was to establish the sanitary condition of soil in the city Dnipro. Subsequently, soil algae of two more cities have been explored: Lugansk (Moskvich, 1973) and Mariupol (Shekhovtseva et al., 2010, 2015). Thus, at present information about the soil algae of urboecosystems of Ukraine is extremely limited. This does not allow us to assess their diversity, to highlight regional features, to find out the degree and main directions of their transformation compared to surrounding non urban areas, and so on. From the perspective of the systematic approach, this reduces the objectivity of characterizing the ecological potential of urboecosystem soils, and, thus, of the prediction of their continued stability and their ability to carry out ecological functions. This is especially true for urban areas of the south of Ukraine, where the phenomena of urbanization in the arid conditions of the steppe zone can accelerate the negative processes of transformation of the soil and biota that inhabit it.

The aim of this work was to study soil the eukaryotic algae and cyanoprokaryotes of various functional zones in an urban ecosystem for developing a comprehensive instrument for monitoring and assessing the ecological state of urban soils and the quality of the urban environment basing the systematic approach and principles of bioindication.

## Materials and methods

The research was carried out in the city of Henichesk, Kherson region (Ukraine). Henichesk is located on the North-Western shore of the Azov Sea. The climate of the region is moderate to continental with mild winters (average January temperature is from –1 °C to –3 °C) and dry, sultry summer (average July temperature is from +22°C to +23°C). Evaporation in the region exceeds the precipitation, therefore, this region has insufficient moisture. The soil cover of the Henichesk is represented by dark chestnut soils and their complexes with solonetz soil. The flora of higher plants of Henichesk in comparison with that of the surrounding area has acquired specific features on the level of systematic, ecological and biomorphological structures which are characteristic for urban flora (Maltseva, 2015; 2016; Maltseva et al., 2017).

To determine the characteristics of the soil algae (eukaryotic and prokaryotic) composition of Henichesk, we have collected the samples from sample plots (SP in different functional areas: residential, industrial, transport, recreational zones and zone of special use: SP 1 – roadside lawns at the entrance to the city from the direction of the village Novooleksiyivka (transport); SP 2 – cemetery (zone of special use); SP 3 – the stadium of the boarding school (residential); SP 4 – the lawn of the Afghan Glory Park (recreational); SP 5 – roadside lawns on Kurazov Street (residential); SP 6 – roadside lawns at the entrance to the city from the direction of the village Frunze (transport); SP 7 – the edge of the road at the entrance to the city from the direction of the village Frunze (transport); SP 8 – the park named after T. G. Shevchenko (recreational); SP 9 – port (industrial).

Each sample plot was 10–50 $m^2$. Three combined samples were sampled for each sample plot (one combined sample consisted of five individual ones). The volume of each individual sample was 25 $cm^3$. The soil was sampled from layers of 0–5, 5–10 and 10–15 cm according to the method shown in the monograph M. M. Gollerbach and E. A. Shtina (1969).

For the investigation of the species composition of the algae, the method of culturing for growth on glasses and accumulation cultures on Bold agar medium (3N BBM) was used. The algae species were identified at 900 and 1000 times magnification, using oil immersion, and were photographed using a Scopetek DCM-510 (5.0 Mpix) digital camera for microscopy. Cells were stained with Lugol solution for presence of starch granules, with 0.1% methylene blue solution and 1% ink solution for determination of the structure of the mucus. For LM investigations of diatoms, the algae were processed by means of a standard procedure involving, treatment with 10% HCl and concentrated $H_2O_2$. The material was washed with distilled water. Permanent diatom preparations were mounted in epoxy resins.

The cultures were grown in a luminaire with fluorescent lamps LB-40 with periodic illumination: 12 hours light and 12 hours dark phase. Dominants and subdominants were established on the basis of abundance scale. Dominant species had a score of «7» and «6», and subdominants – «5» and «4».

We used the taxonomic system of blue-green algae (Cyanoprocaryota) in accordance to the reports of I. Komarek and A. Anagnostidis (Komárek and Anagnostidis, 2005; Komárek, 2013), the rest of the groups – according to «Algae of Ukraine» (Tsarenko et al., 2006, 2009, 2011, 2014).

Analysis of the floristic commonality of the algal species composition was carried out using the Jaccard index for the complete species composition of the algae of individual sample plots:

$$Kj(\%) = \frac{N_{AB} \times 100}{N_A + N_B - N_{AB}},$$

where *Kj* – Jaccard index, $N_{AB}$ – number of common species, $N_A$ and $N_B$ – number of species found on one and the other sample plots respectively.

## Results

In total, 50 species of algae were identified in the soils of the urboecosystems of Henichesk: Cyanoprocaryota – 21, Chlorophyta – 13, Charophyta – 2, Eustigmatophyta – 1, Xanthophyta – 11, Bacillariophyta – 2. The calculated Jaccard index of commonality for the complete algal species list indicates a very high specificity of the algal composition of the studied ecotopes in the city. The most specific composition of algae was noted in the soil of SP 9 «port» situated in the industrial zone. Other ecotopes have a greater similarity among themselves in the species structure but they have a distinct specificity, which is caused by different types of anthropogenic factors.

There were 17 species of algae identified in the soils of the Henichesk transport zone: Cyanoprocaryota – 5, Chlorophyta – 6, Charophyta – 1, Eustigmatophyta – 1, Xanthophyta – 2, Bacillariophyta – 2. The dominant species were: *Chlorella vulgaris* Beij., *Microcoleus vaginatus* (Vaucher) Gomont, *Phormidium paulsenianum* J. B. Petersen, *Chlorococcum* sp. The subdominants were: *Hantzschia amphioxys* (Ehrenb.) Grunow in Cleve et Grunow, *Phormidium* cf. *autumnale* (S. Agardh) Gomont, *Bracteacoccus minor* (Chodat) Petrová (Fig. 1), *Stichococcus bacillaris* Nägeli. Maximum species diversity was noted in the average of the studied soil horizons (5–10 cm). The remaining soil horizons were inhabited by a smaller number of algae species.

The composition of the soil algae of the residential zone includes 17 species: Cyanoprocaryota – 8, Chlorophyta – 3, Charophyta – 1, Eustigmatophyta – 1, Xanthophyta – 3, Bacillariophyta – 1. The list of dominant species was represented by: *Nostoc paludosum* Kütz. ex Bornet et Flahault, *N. punctiforme* (Kütz. ex Hariot) Hariot, *Hantzschia* *amphioxys*, *Phormidium paulsenianum*, *Phormidium retzii* J. Agardh ex Gomont, and subdominants: *Eustigmatos magnus* (J. B. Petersen) D. J. Hibberd (Fig. 2), *Cylindrospermum stagnale* (Kütz.) Bornet et Flahault, *Nostoc punctiforme*, *Klebsormidium flaccidum* (Kütz.) P. C. Silva et al. The distribution of species richness along the soil horizons in different sample plots of the residential area was different. The maximum number of species was recorded in the upper or in the middle studied horizons (5–10 cm).

The species richness of algae in the recreational zone was represented by 16 species: Cyanoprocaryota – 8, Chlorophyta – 3, Charophyta – 1, Eustigmatophyta – 1, Xanthophyta – 3, Bacillariophyta – 1. The dominants were: *Hantzschia amphioxys*, *Chlorococcum* cf. *Echinozygotum* R. C. Starr, *Nostoc linckia* (Roth) Bornet et Flahault, *Tetracystis aggregata* R. M. Br. et H. C. Bold, the subdominants were: *Phormidium bohneri* Schmidle, *Symploca muscorum* (C. Agardh) Gomont, *Nostoc paludosum* (Fig. 3), *Botrydiopsis eriensis* J. Snow. The maximum algal species richness was noted in the middle (5–10 cm) or in the lower (10–15 cm) investigated soil horizons.

In the zone of special use, 9 algae species were identified: Cyanoprocaryota – 2, Chlorophyta – 2, Charophyta – 2, Eustigmatophyta – 1, Xanthophyta – 1, Bacillariophyta – 1. The dominants were *Klebsormidium dissectum* (Gay) Ettl et Gärtner, *K. flaccidum*, *Hantzschia abundans* Lange-Bertalot (Fig. 4). Subdominants were: cf. *Mychonastes homosphaera* (Skuja) Kalina et Punchoch., *Phormidium* cf. *autumnale*. The largest number of algal species was found in the middle five-centimeter deep layer of soil (5–10 cm).

**Table**

Jaccard index of commonality for the full algae list in the different soil samples of the city Henichesk

| Sample plots | SA 1 | SA 2 | SA 3 | SA 4 | SA 5 | SA 6 | SA 7 | SA 8 | SA 9 |
|---|---|---|---|---|---|---|---|---|---|
| SA 1 | 8 | 2 | 1 | 1 | 1 | 2 | 1 | 2 | – |
| SA 2 | 13,3 | 9 | 1 | 1 | 2 | 1 | 2 | 1 | – |
| SA 3 | 5,8 | 5,5 | 10 | 2 | 2 | 1 | 2 | 1 | 1 |
| SA 4 | 6,6 | 6,3 | 12,5 | 8 | 1 | 1 | 2 | 1 | 1 |
| SA 5 | 6,2 | 12,5 | 4,7 | 6,3 | 9 | 1 | 1 | 2 | – |
| SA 6 | 14,2 | 6,2 | 5,8 | 6,6 | 6,3 | 8 | 2 | 1 | – |
| SA 7 | 8,3 | 16,6 | 15,3 | 18,1 | 7,6 | 18,1 | 5 | 2 | – |
| SA 8 | 13,3 | 5,8 | 5,5 | 6,2 | 12,5 | 6,3 | 16,6 | 9 | – |
| SA 9 | – | – | 6,6 | 7,6 | – | – | – | – | 6 |

Note: on the diagonal – number of species of algae on SA; over the diagonal – the number of common species in the comparative lists; under the diagonal – the value of the Jaccard index of commonality.

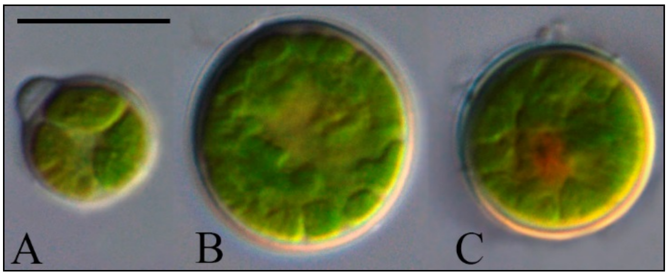


**Fig. 1.** Light micrographs of *Bracteacoccus minor*. A. Young vegetative cell: local swelling on the cell wall ("bubble"). B. Mature vegetative cell with parietal plastids. C. Old cell: red pigments in the center of the cell: scale bar = 10 µm; chestnut soil, horizon 0–5 cm, steppe area adjacent to the road P47 (SA 1), Henichesk (Kherson region, Ukraine) N46°10'30.99" E34°46'12.12"

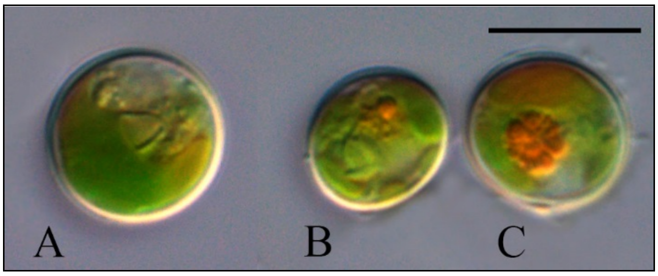


**Fig. 2.** Light micrographs of *Eustigmatos magnus*. A. Young vegetative cell: angulate protein crystal in the center of the cell. B–C. Mature vegetative cell with orange storage compounds; scale bar = 10 µm; soil, horizon 0–5 cm, the residential zone (SA 3), Henichesk (Kherson region, Ukraine) N46°10'17.77" E34°48'33.94"

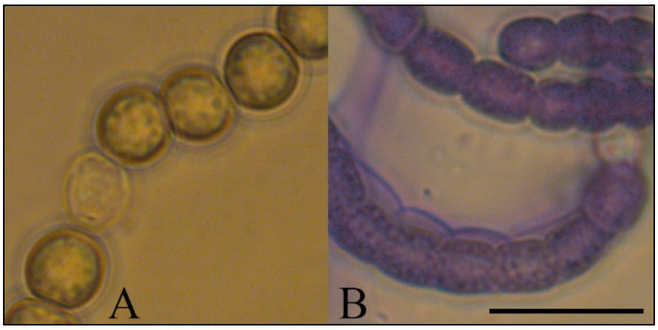


**Fig. 3.** Light micrographs of *Nostoc paludosum*. A. Part of single trichome with intercalary heterocyst. B. Filaments with mucilaginous covering; this is visible after staining with myelene blue; scale bar = 10 µm; sandy soil, horizon 0–5 cm, the recreational zone (SA 8), Henichesk (Kherson region, Ukraine) N46°10'4.39" E34°49'7.23"

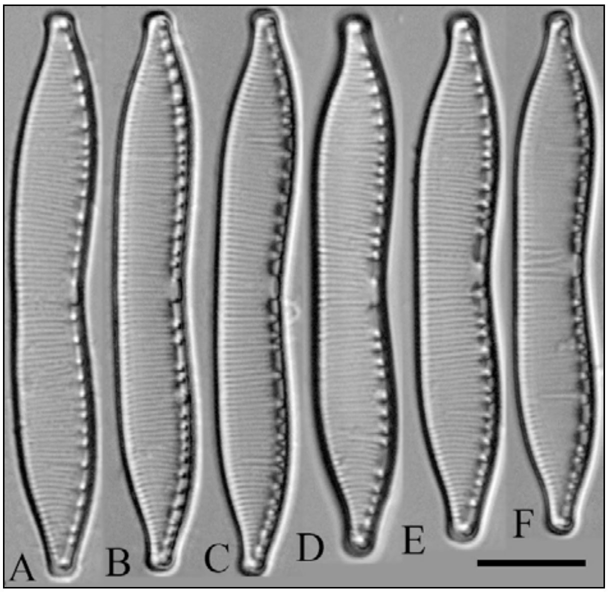


**Fig. 4.** Valve morphology of *Hantzschia abundans*. A–F – light micrographs: the valves are dorsiventral with a convex dorsal side and a ventral side that is distinctly concave in the middle but convex towards the ends; scale bar = 10 µm; chestnut soil, horizon 0–5 cm, city cemetery (SA 2), Henichesk (Kherson region, Ukraine) N46°9'57.72" E34°47'34.78"

Six species of algae were identified in the industrial zone: Cyanoprocaryota – 4, Chlorophyta – 1, Eustigmatophyta – 1. The dominant species were *Microcoleus vaginatus*, *Nostoc* cf. *commune* Vaucher ex Bornet et Flahault and the subdominants were: *Jaaginema pseudogeminatum* (G. Schmid) Anagn. et Komárek, *Eustigmatos magnus*, *Tetracystis* sp. The upper soil layers (0–5 and 5–10 cm) were characterized by depleted algae species richness. Only two species were found. At a depth 10–15 cm there were four algae species.

## Discussion

Combining various natural and variously anthropogenically altered, artificially created biotopes, urban ecosystems represent an interesting object of scientific research. Ecological niches of urban ecosystems are quite complex and diverse in volume and parameters. Various organisms, including eukaryotic and prokaryotic algae, colonise them. The wide variety of various artificial substrates in urban areas (concrete, asphalt, etc.) makes it possible to carry out detailed studies of algal diversity and ecology (Gaylarde et al., 2000; Crispim et al., 2003, 2004; Crispim et al., 2004; Rindi et al., 2004; Uher et al., 2005; Gaylarde et al., 2005; Häubner et al., 2006; Menendez et al., 2006; Karsten et al., 2007; Rindi, 2007; Hallmann et al., 2011). Before these studies, algae were well known as pioneer organisms which appear on the surface of various substrates, including the substrates which were formed after industrial activity and with toxic properties (Gollerbakh et al., 1969; Maltseva et al., 2011; Maltseva et al., 2014). At the same time, algae are included as a part of the soil biota in urban ecosystems. Their diversity and functioning can be significantly disturbed under the impact of urban factors. Data obtained by different researchers (Kabirov et al., 1997; Suhanova et al., 2000, 2011; Sharipova et al., 2004; Rahmatullina et al., 2009; Aksenova et al., 2010; Shekhovtseva et al., 2010; Truhnitskaya et al., 2012; Dorokhova et al., 2015; Bachura et al., 2015; Antipina, 2016) indicates the presence of specific features in the algal composition of urboecosystems. It is determined by the peculiarities of anthropogenic inflluence on soils of urban areas. Physical and chemical transformation is typical for urban soils. This appears, first of all, in the destruction of the profile structure, the presence of anthropogenic inclusions, increase in density, changes in biological parameters, pH values, humus content, accumulation of heavy metals, other toxic substances, etc. (Stroganova et al., 1997, 2003; Shekhovtseva et al., 2015). The degree of degradatory changes and their orientation depend on the specificity and intensity of use of the territory of any given urban ecosystem.

Researchers into urban soil algae indicate that it loses features of zonal type soils, and is characterized by lower species richness. In Henichesk a low algal species richness was noted compared with the protected steppe ecosystems of Askania-Nova reserve (Scherbina, 2011; Maltseva et al., 2011; Scherbina et al., 2014; Maltsev et al., 2017). One sample plot has on average about 8 algae species in Henichesk, while for the steppe ecosystems of Askania-Nova the average number is 35–38 algae species.

Thus, a sharp decrease in the species richness of eukaryotic algae and cyanoprokaryotes is characteristic for soils of urban areas. It can be used as an indicator of anthropogenic disturbance of the ecological usefulness of soils in urban areas. The degree of transformation can be measured by a coefficient that reflects the percentage of conservation of species richness in a particular urban area relative to the background indicators of the species richness of algae. In our studies, this coefficient varies in the range from 13.7% to 27.4%. Low values of the coefficient indicate a significant change in the composition of soil biota and, accordingly, low ecological resistance of soils to the effects of factors of urban origin.

Another specific feature of the flora of urban soil is the prevalence of green algae and representatives of Cyanoprocaryota, the absence or weak development of Xanthophyta species. The common features of the Henichisk urban areas with other urban ecosystems are also the prevalence of Cyanoprocaryota and Chlorophyta species. The absence of Xanthophyta in the composition of algae species is one of the most characteristic features of the aerotechnogenic soil contamination (Shekhovtseva et al., 2010). Changes in pH-values towards alkaline are common for urban soils (Shekhovtseva et al., 2015). The increase of diversity of Cyanoprocaryota representatives is observed during the growth of alkalinity and the pollution of heavy metals in soils.

Thus, in the soil algal flora of urban areas species with the highest adaptability to the influence of various unfavourable factors account for most of the diversity: Cyanoprocaryota and Chlorophyta. The impact of anthropogenic factors takes on a dominant role in urban ecosystems and reduces the edificative role of higher vegetation. In natural communities, arboreal or grassy higher vegetation, through direct and indirect effects, determines many features of algal communities, including the composition of the orders which dominate by the quantity of species (Gollerbach et al., 1969; Maltseva et al., 2011; Scherbina, 2011; Scherbina et al., 2014; Maltsev et al., 2017).

In addition to pollution, one of the common negative effects of anthropogenic impact on soil algae of urboecosystems is recreational pressure. As a result of trampling, the soil is compacted, which leads to a decrease in species richness, the dominance of green algae (Ilyushenko, 2001; Fomina, 2013; Bachura et al., 2015). Another consequence of the compaction of the upper layers of the soil, as well as its contamination, is the change of the profile distribution of algae species richness. The greatest diversity of eukaryotic and prokaryotic algae species in the soil is usually present in its upper layer because they are photosynthetic organisms. However, the composition of the soil biota of the upper horizon is depleted as a result of anthropogenic changes of the soil in urban conditions, its contamination and compaction of the upper layers. This upper layer is characterized by the greatest biological activity in undisturbed areas. This atypical picture of the profile distribution of algae indicates a sufficiently strong expression of negative changes in the upper layers of soil in the city and the inadequate compensatory capacity of soil biota communities in relation to the influence of anthropogenic factors. Different types of city territory use are characterized by different depths of transformational changes in the soil and its biota. This is reflected in the species richness of algae, and variations in the composition of dominant species. Among the dominants and subdominants of the recreational and transport zone were species of different orders. The dominants and subdominants of the residential and industrial zones were representatives of Cyanoprocaryota and in the zone of special use – Chlorophyta species.

The poorest species structure of algae in Henichesk was marked in the industrial zone. This fact also has been noted in other cities (Sharipova et al., 2004, Shekhovtseva et al., (2015). The distinction of the urbanized soils of Henichesk , in comparison with others, is the sufficiently high diversity of algae in the transport zone and low diversity in the zone of special use. The latter fact is connected with additional anthropogenic load on the soil of this territory from a nearby highway, railways and coal storage. These objects are the sources of aerotechnogenic pollution and exert a negative impact on the diversity of soil biota.

The obtained data indicate that algae as an essential part of the soil biota are sufficiently sensitive to changes in soil caused by the impact of urban factors. Therefore, in assessing the ecological conditions and classification of urban soils, data on their species richness, the composition of dominants, and their distribution features in the soil profile should be taken into account.

## Conclusion

Questions related to the assessment of the ecological conditions of soils are highly relevant in studying urban ecosystems.

It is established that changes in the composition of algae in soils of urban ecosystems are one of the indicators of the presence and degree of transformation of soil biota and soil as a whole under conditions of urban ecosystems and can be used as indicators in the environmental assessment of urban soils, the development and subsequent examination of ways to reduce the negative manifestations of urbanization. Using data from algological studies of urban ecosystems, along with others, in accordance with the principles of the system approach, will contribute to optimizing the urban environment, ensuring the full value of its bioecological potential.

50 species of algae were identified in the soils of the Henichesk: Cyanoprockaryota – 21, Chlorophyta – 13, Charophyta – 2, Eustigmatophyta – 1, Xanthophyta – 11, Bacillariophyta – 2. Anthropogenic pressure on urban soils reduces the diversity of algae. Characteristic feature of the urbanized flora of Henichesk, as well as other urboecosystems, is the low algal species richness compared with natural reference areas, as well as the prevalence of Cyanoprocaryota and Chlorophyta species. Considering that soil biota, on the one hand, depends on the ecological conditions of the soil, and on the other hand, as a result of its vital activity, changes the ecological functions of the soil, enhancing or weakening them, soils of the urboecosystems are limited in their ecological functions, due to the reduction of algal species richness.

The degree of urban transformation of soil biota and directly of soil algae can be expressed through a coefficient that reflects the percentage of conservation of species richness in a particular urban area relative to the background indicators of species richness. Another indicator that can be used in the bioindication of urban soils is the increase in diversity of Cyanoprocaryota and Chlorophyta species. Representatives of these orders are characterized by a high adaptive capacity for various unfavourable factors observed in urban ecosystems.

It is established that the algal flora of urban soils lose their zonal features and features associated with the edificative influence of higher vegetation. The distribution of species richness of algae along the soil profile in the city territory acquires an atypical character. There is an increase in the species richness of algae not in the upper soil layers, but in the lower, aphotic parts of the soil profile. This indicates a strong expression of negative changes in the upper soil layers in the city and the suppression of the soil biota under the influence of anthropogenic factors of urban origin.

The most diverse algal species composition in the territory of Henichesk was noted in the recreational, residential and transport zones, in comparison with the industrial zone and the zone of special use. Among the dominant and subdominant were Cyanoprocaryota and Chlorophyta species. Other phyla were represented by *Klebsormidium dissectum*, *K. flaccidum*, *Hantzschia amphioxys*, *Eustigmatos magnus*, *Botrydiopsis eriensis*.

## References


Aksenova, N. P., & Baranova, O. G. (2010). Kratkiy obzor urbanofloryi edafofilnyih vodorosley i tsianoprocariot g. Izhevska [A brief review of the urban floras of edaphophylic algae and cyanoprokaryotes of Izhevsk]. Vestnik Udmurtskogo Universiteta. Biologiya. Nauki o Zemle, 1, 27–31 (in Russian).

Aksoya, E., Louwagieb, G., Gardic, C., Gregord, M., Schrödera, C., & Löhnertzd, M. (2017). Assessing soil biodiversity potentials in Europe. Science of the Total Environment, 589, 236–249.

Antipina, G. S. (2016). Urbanoflora Petrozovodska: Pochvennyie vodorosli lesnyih uchastkov pri antropogennom vozdeystvii [Urbanoflora of Petrozavodsk: Soil algae of forest areas under anthropogenic impact]. Uchenyie Zapiski Petrozavodskogo Gosudarstvennogo Univesiteta, 159, 27–36 (in Russian).

Bessolitsyna, E. P., & Balyazin, I. V. (2013). Structural-dynamical analysis of the state of the biota of soils in urbanized geosystems (Exemplified by the City of Sayanogorsk). Geography and Natural Resources, 34(2), 137–143.

Blagodatnova, A. G., & Bachura, Y. M. (2015). Fitotsenoticheskaya struktura gruppirovok pochvennyih vodorostey i tsianobakteriy gorodskih gazonov (na primere g. Novosibirska i g. Gomelya) [Phytocenotic structure of groups of soil algae and cyanobacteria of urban lawns (on the example of Novosibirsk and the city of Gomel)]. Vestnik Novosibirskogo Gosudarstvennogo Pedagogicheskogo Universiteta, 25, 82–93 (in Russian).

Caruso, T., Migliorini, M., Rota, E., & Bargagli, R. (2017). Highly diverse urban soil communities: Does stochasticity play a major role? Applied Soil Ecology, 110, 73–78.

Crispim, C. A., & Gaylarde, C. C. (2004). Cyanobacteria and biodeterioration of cultural heritage: A review. Microbial Ecology, 49(1), 1–9.

Crispim, C. A., Gaylarde, C. C., & Gaylarde, P. M. (2004). Biofilms on church walls in Porto Alegre, RS, Brazil, with special attention to cyanobacteria. International Biodeterior and Biodegradation, 54, 121–124.

Crispim, C. A., Gaylarde, P. M., & Gaylarde, C. C. (2003). Algal and cyanobacterial biofilms on calcareous historic buildings. Current Microbiology, 46(2), 79–82.

Dorokhova, M. F., Kosheleva, N. E., & Terskaya, E. V. (2015). Algae and cyanobacteria in soils of Moscow. American Journal of Plant Sciences, 6(15), 2461–2471.

Fomina, N. V. (2013). Mikrobiologicheskiy analiz pochvyi rekreatsionnyih zon krasnoyarskoy urboekosistemyi [Microbiological analysis of soil in the recreational zones of the Krasnoyarsk urban ecosystem]. Vestnik KrasGAU, 11, 80–85 (in Russian).

Gaylarde, C. C., & Gaylarde, P. M. (2005). A comparative study of the major microbial biomass of biofilms on exteriors of buildings in Europe and Latin America. International Biodeterior and Biodegradation, 55(2), 131–139.

Gaylarde, P. M., & Gaylarde, C. C. (2000). Algae and cyanobacteria on painted buildings in Latin America. International Biodeterior and Biodegradation, 46(2), 93–97.

Gollerbah, M. M., & Shtina, E. A. (1969). Pochvennyie vodorosli [Soil algae]. Nauka, Leningrad (in Russian).

Gorovits-Vlasova, L. M. (1927). K voprosu o sanitarnom izuchenii gorodskih pochv (issledovanie pochvyi g. Dnepropetrovska) [The issue about the sanitary study of urban soils (study of soil in Dnepropetrovsk)]. Gigiena i Epidemiologiya, 8, 66–71 (in Russian).

Gorovtsov, A., Rajput, V. D., Gorbov, S., & Vasilchenko, N. (2017). Bioindication-based approaches for sustainable management of urban ecosystems. In: Singh, R., Kumar, S. (Eds.). Green Technologies and Environmental Sustainability. Springer.

Hallmann, C., Rüdrich, J., Enseleit, M., Friedl, T., & Hoppert, M. (2011). Microbial diversity on a marble monument – A case study. Environmental Earth Sciences, 63(7–8), 1701–1711.

Häubner, N., Schumann, R., & Karsten, U. (2006). Aeroterrestrial miroalgae growing in biofilms on facades – Response to temperature and water stress. Microbial Ecology, 51(3), 285–293.

Ilyushenko, A. E. (2001). Prisposobleniya pochvennyih vodorosley lesnyih fitotsenozov k rekreatsionnyim nagruzkam [Adaptations of soil algae from the forest phytocenoses to recreational preassure]. Sibirskiy Ekologicheskiy Zhurnal, 4, 443–448 (in Russian).

Joimel, S., Schwartz, C., Hedde, M., Kiyota, S., & Cortet, J. (2017). Urban and industrial land uses have a higher soil biological quality than expected from physicochemical quality. Science of The Total Environment, 584–585, 614–621.

Kabirov, R. R., & Suhanova, N. V. (1997). Pochvennyie vodorosli gorodskih gazonov [Soil algae of urban lawns]. Botanicheskiy Zhurnal, 82(3), 46–57 (in Russian).

Karsten, U., Schumann, R., & Mostaert, A. (2007). Aeroterrestrial algae growing on man-made surfaces. In: Seckbach, J. (Ed.). Algae and Cyanobacteria in extreme environments. Cellular Origin, Life in Extreme Habitats and Astrobiology. Vol 11. Springer, Dordrecht.

Komárek, J., & Anagnostidis, K. (Eds.). (2005). Cyanoprokaryota. Part 2: Oscillatoriales. Springer Spektrum, Heidelberg.

Komárek, J., Büdel, B., Gärtner, G., Krienitz, L., & Schagerl, M. (Eds.). (2013). Cyanoprokaryota, Part 3: Heterocytous Genera. Springer Specktrum, Berlin, Heidelberg.

Li, B., Wu, S., Zhou, S., Wang, T., & Chen, H. (2017). Quantifying and mapping threats to soilbiodiversity in Nanjing, China. European Journal of Soil Biology, 82, 72–80.

Maltsev, Y. I., Pakhomov, A. Y., & Maltseva, I. A. (2017). Specific features of algal communities in forest litter of forest biogeocenoses of the Steppe zone. Contemporary Problems of Ecology, 10(1), 71–76.

Maltseva, I. A., & Baranova, O. A. (2014). Vodorosli tehnogennyih ekotopov zhelezorudnogo proizvodstvan [Algae of man-made ecotop of iron ore production]. Algologiya, 24(3), 350–353 (in Russian).

Maltseva, I. A., & Scherbina, V. V. (2011). Vodorosti viddilu Cyanophyta deyakyx ob'yektiv pryrodno-zapovidnogo fondu pivdnya Ukrayiny [Cyanophyta of some objects of the nature reserve fund of the south part of Ukraine]. Gruntoznavstvo, 12(1–2), 78–80 (in Ukrainian).

Maltseva, I. A., & Chayka, N. I. (2011). Pochvennyie vodorosli otvala ugolnoy shahtyi Donetskoy oblasti [Soil algae of blade of coil in Donetsk region]. Visnyk Melitopolskogo Derzhavnogo Pedagogichnogo Universytetu imeni Bogdana Hmelnyckogo, 1(3), 45–54 (in Russian).

Maltseva, S. Y. (2015). Ohranjaemye i redkie vidy v urbanoflore Genicheska [Rare and protected species in urban flora of Genichesk]. Biological Bulletin of Bogdan Chmelnitskiy Melitopol State Pedagogical University, 5(1), 105–114 (in Russian).

Maltseva, S. Y. (2016). Dendroflora Geniches'ka (Herson'ka oblast', Ukraina) [Dendroflora of Genichesk (Kherson region, Ukraine)]. Visnyk of Kharkov National Agrarian University. Series Biology, 38, 106–114 (in Ukrainian).

Maltseva, S. Y., & Maltsev, Y. I. (2017). Novi znahidky u flori mist Pivnichnogo Pryazov'ja [New findings in urban flora of Northern Azov Sea region]. Ukrainian Journal of Ecology, 7(2), 55–58 (in Ukrainian).

Menendez, J. L., Rindi, F., Rico, J. M., & Guiry, M. D. (2006). The use of CHAID classification trees as an effective descriptor of the distribution of *Rosenvingiella radicans* (Prasiolales, Chlorophyta) in urban environments. Cryptogamie Algologie, 27, 153–164.

Meuser, H. (2010). Assessment of urban soils. In: Contaminated Urban Soils. Environmental Pollution, Vol. 18. Springer, Dordrecht.

Moskvich, N. P. (1973). Opyit ispolzovaniya vodorosley pri izuchenii sanitarnogo sostoyaniya pochv [Experience in the use of algae in studying of the sanitary state of soils]. Botanicheskiy Zhurnal, 58(3), 412–416 (in Russian).

Rahmatullina, I. V., & Kuznetsova, E. V. (2009). Rezultatyi issledovaniy pochvennoy algofloryi Yuzhnogo regiona Respubliki Bashkorstan [Results of soil algal flora research in the Southern Region of the Republic of Bashkortostan]. Vestnik OGU, 100, 594–596 (in Russian).

Rindi, F. (2007). Diversity, distribution and ecology of Green Algae and Cyanobacteria in urban habitats. In: Seckbach, J. (Eds.). Algae and Cyanobacteria in Extreme Environments. Cellular Origin, Life in Extreme Habitats and Astrobiology, Vol. 11. Springer, Dordrecht.

Rindi, F., & Guiry, M. D. (2004). Composition and spatial variability of terrestrial algal assemblages occurring at the bases of urban walls in Europe. Phycologia, 43(3), 225–235.

Scherbina, V. V. (2011). Dynamika chyselnosti ta biomasy vodorostej stepovyx biogeocenoziv ta agrocenoziv Hersonskoyi oblasti [Dynamics of algal biomass and quantity in the steppe biogeocenoses and agrocenoses of the Kherson region]. Biologichnyj Visnyk Melitopolskogo Derzhavnogo Pedagogichnogo Universytetu imeni Bogdana Xmelnyczkogo, 3, 80–86 (in Ukrainian).

Scherbina, V. V., Maltseva, I. A., & Solonenko, A. N. (2014). Peculiarities of postpyrogene development of algae in steppe biocenoses at Askania Nova Biospheric National Park. Contemporary Problems of Ecology, 7(2), 187–191.

Sharipova, M. Y., & Dubovik, I. E. (2004). Kompleksnoe issledovanie algofloryi g. Ufyi [Comprehensive research of algoflora in Ufa]. Vestnik Bashkirskogo Universiteta, 4, 45–50 (in Russian).

Shekhovtseva, O. G., & Maltseva, I. A. (2010). Aerotehnogennoe izmenenie himicheskih pokazateley poverhnostnogo gorizonta pochv – osnovnogo mesta suschestvovaniya pochvennyih vodorostey (na primere urboekosistem g. Mariupolya) [Aerotechnogenic change in the chemical characteristics of the surface horizon of soils – the main site for the existence of soil algae (on the example of urboecosystems in Mariupol)]. Gruntoznavstvo, 11(1–2), 91–96 (in Russian).

Shekhovtseva, O. G., & Maltseva, I. A. (2015). Physical, chemical, and biological properties of soils in the city of Mariupol, Ukraine. Eurasian Soil Science, 48(12), 1393–1400.

Stankovic, S., & Stankovic, A. R. (2013). Bioindicators of toxic metals. In: Lichtfouse, E., Schwarzbauer, J., & Robert D. (eds). Green Materials for Energy, Products and Depollution. Environmental Chemistry for a Sustainable World. Vol. 3. Springer, Dordrecht.

Stroganova, M. N., & Myagkova, A. D. (1996). Vliyanie negativnyih ekologicheskih protsessov na pochvyi goroda (na primere Moskvyi) [Influence of negative ecological processes on city soils (on the example of Moscow)]. Pochvovedenie, 17(4), 37–45 (in Russian).

Stroganova, M. N., Myagkova, A. D., & Prokof'eva, T. V. (1997). The role of soils in urban ecosystems. Eurasian Soil Science, 30(1), 82–86.

Stroganova, M. N., Prokof'eva, T. V., Lysak, L. V., Prokhorov, A. N., Yakovlev, A. S., & Sizov, A. P. (2003). Ecological conditions of urban soils and economic evaluation of lands. Eurasian Soil Science, 36(7), 780–787.

Suhanova, N. V., Fazlutdinova, A. I., & Haybullina, L. S. (2000). Diatomovyie vodorosli pochv gorodskih parkov [Soil diatoms of urban parks]. Pochvovedenie, 7, 840–846 (in Russian).

Suhanova, N. V., Fazlutdinova, A. I., Gaysina, L. A., & Bogdanova, A. V. (2011). Flora pochvennyih vodorosley i tsianobakteriy g. Neftekamsk (Respublika Bashkortostan) [Flora of soil algae and cyanobacteria of Neftekamsk (Republic of Bashkortostan)]. Izvestiya Samarskogo Nauchnogo Tsentra Rossiyskoy Akademii Nauk, 5(2), 115–117 (in Russian).

Truhnitskaya, S. M., & Koreneva, V. V. (2012). Vidovoe raznoobrazie tsianoprokariot rekreatsionnyih territoriy g. Krasnoyarsk [Species diversity of cyanoprocaryotes of recreational areas in Krasnoyarsk]. Vestnik KGPU im. V. P. Astafeva, 3, 347–349 (in Russian).

Tsarenko, P. M., Wasser, S., & Nevo, E. (Ed.). (2006). Algae of Ukraine: Diversity, nomenclature, taxonomy, ecology and geography. Vol. 1. Cyanoprocaryota, Euglenophyta, Chrysophyta, Xanthophyta, Raphidophyta, Dinophyta, Cryptophyta, Glaucocystophora and Rhodophyta. A. R. A. Gantner, Ruggell.

Tsarenko, P. M., Wasser, S., & Nevo, E. (Ed.). (2009). Algae of Ukraine: Diversity, nomenclature, taxonomy, ecology and geography. Vol. 2. Bacillariophyta. A. R. G. Gantner, Rugell, Königstein.

Tsarenko, P. M., Wasser, S., & Nevo, E. (Ed.). (2011). Algae of Ukraine: Diversity, nomenclature, taxonomy, ecology and geography. Vol. 3. Chlorophyta. A. R. G. Gantner, Rugell, Königstein.

Tsarenko, P. M., Wasser, S., & Nevo, E. (Ed.). (2014). Algae of Ukraine: Diversity, nomenclature, taxonomy, ecology and geography. Vol. 4. Charophyta. Koeltz Scientific Books, Königstein.

Uher, B., Aboal, M., & Kovacik, L. (2005). Epilithic and chasmoendolithic phycoflora of monuments and buildings in South-Eastern Spain. Cryptogamie Algologie, 26(3), 275–308.

Wei, H., Liu, W., Zhang, J., & Qin, Z. (2017). Effects of simulated acid rain on soil fauna community composition and their ecological niches. Environmental Pollution, 220, 460–468.