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Assessment of ecological state of Rostov zoo soil

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Abstract

A comparative study of ecological and biological parameters of soils of the Rostov-on-Don Zoo was carried out in 2017-2020. Monitoring sites were studied in areas of various purpose: aviaries with different animals, recreation area, park area. The control plot was a relatively undisturbed park section in the territory of the zoo. Different sites revealed heterogeneity of ecological conditions and soil properties. The most significant difference was in the physical properties of soils. Density, penetration resistance, and soil structure were degraded in aviaries with large animals: rhinos, zebras, deer. Using methods of bioindication, the degree of change in the soil of aviaries was determined compared with the soil of the control plot. The abundance of nitrogen-fixing bacteria of the Azotobacter genus was reduced in the soils of aviaries with zebras, rams, rhinos and giraffe due to the artificial addition of sand to the soil for the purpose of improvement of its physical properties. The activity of soil enzymes (urease and dehydrogenases) was significantly increased in the soils of aviaries due to their contamination with animal excretory products. A particularly high increase was in urease (up to 7.4 times relative to the control soil). The main problems of the topsoil of the zoo are overconsolidation, structural degradation, organic pollution, change in biological activity. The degree of change depends on the size of aviaries, the size and activity of animals and soil amelioration aimed at regulating physical properties of the soil.

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Introduction

The zoo is an integral part of the recreational area of any big city. The purpose of the establishment of this institution was the preservation and reproduction of animals, as well as their demonstration to visitors. In zoos accredited by the Association of Zoos and Aquariums (AZA), there are approximately 750.000 animals representing 6.000 species (AZA, 2016).

An aviary is a location for a certain type of animal. The area should be close to its natural habitat. The closeness to the natural analogue and safety make it possible for animals to feel more comfortable in the conditions of involuntary stay.

Urbanization is currently one of the main factors changing the ecological condition of nature. The condition of vegetation and topsoil in cities draws a lot of attention (Tao et al., 2016; Ivashchenko et al., 2019; Kuznetsov et al., 2019; Momirović et al., 2019). Moreover, studies of urban landscapes are insufficient for optimization of the ecological condition of large metropolises. This is especially true of soil and topsoil. The soils in the large metropolis of Rostov-on-Don with a million inhabitants have not been fully studied. There

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are a number of sources in the literature addressing some soil properties and features of soil formation (Gorbov and Bezuglova, 2014; Gorbov et al., 2015; Bezuglova et al., 2018). Anthropogenic impact significantly changed the properties and process of soil formation in zonal chernozems of the steppe zone of southern Russia. However, these studies were not able to reflect the functional patterns of the soils in the metropolis in full. This is especially true for the biological condition of urban soils. Rostov Zoo – one of the largest zoos in Russia – was founded 90 years ago and is located in the center of a large metropolis (Figure 1). It is a member of 38 conservation programs for rare and endangered species. The Rostov Zoo contains about 5,000 animals belonging to 400 species. The relevance of ecological studies of the territory of the Rostov Zoo is determined by a low degree of exploration, the presence of specific factors of structural and functional organization, intensive anthropogenic impact, the need for a detailed study of the ecological condition.

Figure 1. Layout of monitoring sites in the zoo: 1–zebras; 2-red deer; 3-bharals; 4- birds; 5–camels; 6-children playground; 7– control; 8– emus (2017) later red deer (2018-2019); 9–buffalo; 10–rhinoceros; 11–giraffe; 12–donkeys

There is a lack of studies of zoo soils, despite the significant role of them in the functioning of natural and anthropogenic ecosystems. Keeping animals in aviaries can lead not only to soil degradation, but also to air pollution with ammonia. Earlier, an assessment of the ecological condition of soils in the Moscow Zoo have been carried out (Yurkova et al., 2009). The results of preliminary studies of the territory of the Rostov Zoo were presented earlier (Kazeev et al., 2018).

An incorrectly selected area of the aviaries leads to overcrowding of animals. This negatively affects their habitat, including their impact on the soil cover of the territory. Also, the release of waste from zoo animals can lead to the accumulation of harmful substances in soils (Gustin and Kelley, 1971). Animal waste accumulating on the soil surface reduces the aesthetic appeal of zoos and serves as a source of pathogenic microflora, biotoxins, and unpleasant odors (Yurkova et al., 2009; Conrad et al., 2018). Zoos can be sources of air pollution from animal excrement, manure, and contaminated litter (Buzmakov et al., 2014). Thus, it becomes necessary to monitor the ecological state of the soils of the zoo aviaries in order to improve the living conditions of animals in captivity.

The aim of the study was to assess the ecological condition and function of soils in different areas of the Rostov Zoo.

The influence of animals has been established on the ecological state of the soils of the aviaries. The practical significance of the work is expressed in determining a set of indicators for environmental monitoring of the territory of zoos. Research is important for finding ways to increase the rate of biological processes in the soil in order to remove animal waste products.

Material and Methods

The studies were carried out in 2017-2020 in accordance with the methods of biological diagnostics of the ecological condition of soils (Kazeev et al., 2016). Previously, using this methodology, a study of ecological parameters of the soils in reserves and anthropogenically disturbed territories was performed (Kazeev et al., 2012, 2015, 2020). As a result, several monitoring sites were allocated in the territory of the zoo: aviaries with birds (gray cranes *Grus grus*, peacocks *Pavo cristatus*, brent geese, etc.), Chapman's zebras (*Equus burchelli chapmani*), emus (*Dromaius Vieillot*), red deer (*Cervus elaphus*), Bactrian camels (*Camelus bactrianus*), bharals (*Pseudois nayaur*), Asian buffalo (*Bubalus arnee*), Rothschild's giraffe (*Giraffa camelopardalis*), white rhinoceros (*Rhinocerotidae Gray*) and domestic donkeys (*Equus asinus asinus*). The control site is located in the Park area of the zoo and has the same soil cover and vegetation as in other areas of the zoo and aviaries. At each monitoring site, 3 individual soil samples were taken, and analytical studies were carried out in each of them; they were replicated 3-10 times. The measured indicators included the physical, chemical, physicochemical and biological properties of soils. Soil density was determined by the gravimetric method using steel rings with a volume of 135 cm^3 and replicated 3 times. Soil hardness (penetration resistance, soil structure strength) was studied in the field using an EIJKELKAMP penetrometer on a depth of 50 cm with an interval of 5 cm, replicated 10 times. The structural and aggregate analysis of the soil was carried out using dry sieving of soil through a column of sieves with 10 mm to 0.25 mm meshes. The quality of the soil structure was assessed by the percentage of the sum of soil aggregates with sizes less than 10 and more than 0.25 mm from the total sum of aggregates.

The temperature was determined with a HANNA CHECTEMP electronic thermometer, on the surface of the soil and at a depth of 5 and 10 cm. The moisture content (volumetric) of the soil was determined in the field using a Fieldscout TDR 100 moisture meter from Spectrum Technologies Inc. (USA) in 10-fold repetition on each study site.

Analytical studies were performed at the Department of Ecology and Environmental Management of the Southern Federal University (Rostov-on-Don, Russia) using methods accepted in ecology, biology and soil science (Kazeev et al., 2016). The content of organic carbon in humus was determined using the method of oxidation with a chromic mixture on a spectrophotometer UNICO 1201 (United Products & Instruments, Inc., USA). The reaction of the soil environment (pH) and the redox potential was determined by a potentiometric method (HANNA HI 98128 pHep 5, Germany) in soil suspension with a soil : water ratio of 1 : 2.5 (10 g soil to 25 ml water). The content of easily soluble salts was determined by conductometry on the basis of electrical conductivity (EC) by HANNA HI 9034, Germany. The carbonate content is determined by the volumetric method with the addition of HCl solution (AFNOR X 31-105). The total number of bacteria was determined by the method of luminescent microscopy with sample staining with acridine orange (Merck KGaA, Germany). It should be noted that staining with appropriate dyes allows only the total number of bacteria and fungi in the soil sample to be determined, but not the physiological status of the cells. The green cells of bacteria were counted with a ZEISS inverted microscope, AXIO Vert. A1 model with a 450-490 nm filter (CARL ZEISS, Germany). The intensity of carbon dioxide release – soil respiration was determined according using carbon dioxide as an absorber sodium hydroxide solution. For this purpose, 10 g of moist soil for 24 h was placed in a flask with 0.1 mol×dm^{-3} NaOH solution, which was then titrated with 0.05 mol×dm^{-3} hydrochloric acid solution.

Soil enzymes, dehydrogenases and urease, free-living nitrogen-fixing bacteria of the genus Azotobacter, which are widely used in the diagnostics of the ecological condition of soils (Kazeev et al, 2016; Martinez-Mera et al., 2017; Kolesnikov et al., 2019), were used as bioindicators. The enzymatic soil activity was estimated on the basis of the activity of different enzyme classes: oxidoreductases (dehydrogenase) and hydrolases (urease). Determination of the enzymatic soil activity was based on the amount of the substrate processed during the reaction or the formation of the reaction product under optimal conditions of temperature, pH of the medium, concentration of the substrate and soil hinge. The catalase activity (H_2O_2: H_2O_2-oxidoreductase, EC 1.11.1.6.) was determined by the volumetric method according to the volume of decomposed hydrogen peroxide per 1 min. The activity of dehydrogenases (substrate:NAD(F)-oxidoreductase, EC 1.1.1) was determined using triphenyltetrazolium reduced to triphenylformazane. The urease activity (carbamide-amidohydrolase, EC 3.5.1.5.) was determined by the amount of ammonia formed during the urea hydrolysis. The activity of soil enzymes was studied at the natural soil pH without buffer, in 3–6-fold repetition. The control for determining the activity of enzymes was carried out by the use of substrates without soil.

To combine several parameters, a methodology was used to determine the integral parameter of the biological state (IPBS) of the soil (Kazeev et al., 2015). This method allowed evaluating the set of biological parameters. For this, the value of each parameter in the control soil was taken as 100%. In the soil, this parameter value was expressed as a percentage in relation to it as follows:

$$B1 = \frac{Bx}{Bc} \times 100 \#(1)$$

where B1 is the relative score of the parameter, Bx is the actual value of the parameter in the soil, Bc is the value of the parameter in the control soil.

After that, the average estimated score of the studied parameters for the sample was calculated. The absolute values cannot be summed, since they have different units of measurement (mg, %, etc.). The integral parameter of the biological status of the soil was calculated according to the following formula:

$$B1 = \frac{Ba}{Ba.c} \times 100 \#(2)$$

where Ba – average estimated score of all parameters in post-fire soil, Ba.c – estimated score of all parameters under control.

The biological properties of the soil are characterised by a high degree of variation. Therefore, in order to obtain reliable data, thorough statistical processing is required. We determined the parameters of variation and carried out a correlation analysis. Statistical processing of the obtained results was carried out using Statistica 10.0. We used the arithmetic average value (M), and standard error of the mean (m). A correlation analysis was used to study the closeness and shape of the relationship between various parameters of the ecological and biological status of the soil. Statistical data processing was performed using Statistica 10.0 and Python 3.6.5.

Results and Discussion

The soil of the study areas is represented by ordinary heavy loamy chernozems (Haplic Chernozems). Some aviaries (zebras, rhinos, giraffe and bharals) had different amounts of sand added to the soil surface to improve the water-physical condition. The control site is located in the center of the zoo in a park area with a vegetation and topsoil characteristic of most of the territory of the zoo (Figure 2). The recreationally disturbed site is located 50 m from the control site and is characterized by a significant disturbance of the soil surface due to the construction of the playground here. The soil surface is most severely disturbed in the aviaries with deer and buffalo, which have significantly impacted the soil surface with their sharp hooves (Figure 3), as well as in aviaries with other large ungulates (rhinos, zebras), where river sand was added to improve the physical properties of the soil.

Figure 2. Zoo control site on May 2019.

Figure 3. Disturbed soil in the aviary with a male deer on May 2019.

The studies showed differences in ecological conditions and physical properties of the soils of the study area. The moisture content of the topsoil varied widely depending on the season of the year. In autumn and spring, soil moisture was high (an average of 20-22%), in the summer months, moisture decreases to its critical values for biological processes (less than 13%). However, year by year, soil moisture can vary greatly even in one month of observation. For example, in May 2018, due to the large amount of precipitation in the spring, soil moisture averaged 21.3% (the values ranged in different areas from 16.1 to 36.0), and in dry May of 2019, the soil moisture was much lower at 7.4% (the values ranged from 3.4 to 10.4%). The temperature of the soils varied even more drastically, both on the surface and throughout the soil profile. Under the conditions of the Rostov Zoo, the reaction of the soil was the most conservative indicator. In all the study areas, pH fluctuated in a small range from 7.4 to 7.8. The concentration of highly soluble salts in the soils of animal aviaries is slightly increased relative to the soils of the control plots. However, the difference in values is insignificant, although more pronounced when sampling in the dry season.

The density of the soil was the most representative parameter, reflecting the degree of disturbance of the topsoil on the territory of a number of zoo sites. This indicator is closely related to structure and porosity indicators and is one of the most important indicators of the ecological condition of soils. In all animal aviaries, soil density was increased relative to control values (Figure 4, 5). Here, the values reached high values up to 1.5-1.6 g cm^{-3}. Only in aviaries with birds bulk density was at the level of control values. This is easily explained by the size of animals and their level of mobility. Large animals exert high pressure on the soil, causing the destruction of its surface layer. However, the degree of compaction depends not only on the size of the animals, but also on their activity and the shape of the hooves. The relatively small and sharp hooves of deer and zebras create a greater destructive effect on the soil than larger camels with a wide and soft hoof. Keeping animals in aviaries significantly affects the structure of soils. All sites with animals and birds differ from the control site in a lower content of 1 to 10 mm aggregates. These aggregates determine the quality of the soil structure. In aviaries with large animals, the soil structure was also changed from lumpy (as in control) to blocky. Disturbance in the soil structure of the aviary with medium-sized birds kept together (cranes, peacocks, brent geese, chickens, etc.) is greater than that exerted by several large emus (Figure 6). That is, the effect on the soil is associated with both the size of the birds kept, and their number in the aviary, as well as the size of the aviary. Water resistance of aggregates is significantly reduced when sand is added to the soil.

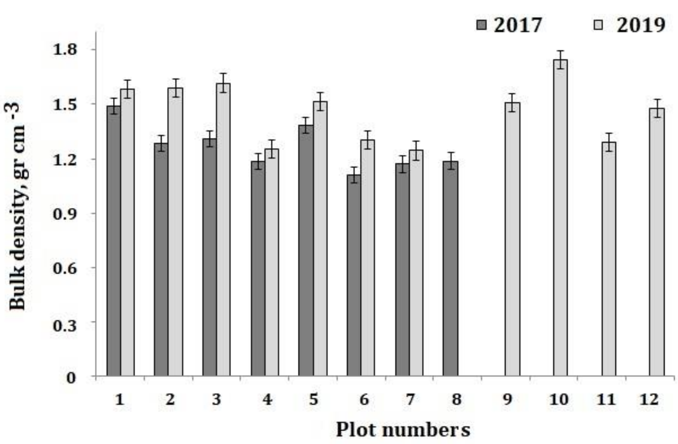

Figure 4. Bulk density values in different plots given in figure 1, May 2019

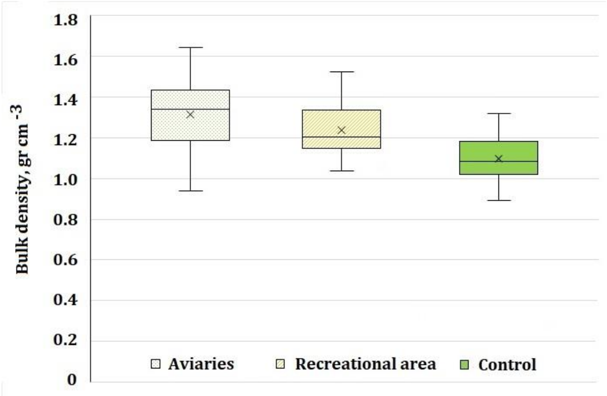

Figure 5. The bulk density of the soil in different zones of the zoo, 2017-2020

The reason for the change in the physical properties of soils is animals that have a direct impact on the soil cover in the aviaries where they live. The ratio of the number of animals and their total weight, which they load on the soil surface, to the area of the aviaries, shows the strength of the effect of this factor on the increase in density in the investigated aviaries (table).

Buffaloes have a maximum impact on the soil -5.5 kg.m^{-2}, in the rhino aviary -2.8 kg.m^{-2}. Significantly less impact in aviaries with other animals. The minimum calculated load falls on the aviary with birds - 0.08 kg.m^{-2}. In addition to the size of the animal, its activity is also of great importance, as well as the direct pressure of the hooves on the soil, which depends on the weight of the animal and the size of its hooves. The relatively small and sharp hooves of deer and zebras create more damaging effects on the soil than a larger camel with a wide and soft hoof.

A significant amount of animal metabolism products enter the soil surface in aviaries (Table 1). During the year, animals introduce into the soil from 2.7 to 97.8 kg of waste per unit area. This is a significant contribution to the replenishment of organic compounds in the soils of the aviaries. The maximum biogenic pollution was found in the buffalo aviaries. In the sheep aviaries, the intake of animal waste is minimal among all aviaries (2.7 kg.m^{-2}.year^{-1}). Despite the daily cleaning, it is not possible to completely remove animal waste products. The flow of urine into the soils of the aviaries is very high due to the limited size of the aviaries. An important role is played by the specificity of animals, which determines their physiology. So for mammals and birds, the chemical composition of the secretions is different, which also matters.

In a zoo, the habitat of animals is significantly reduced. At the same time, the physiological characteristics of the inhabitants remain the same. The aviary and overcrowding of animals leads to the accumulation of nutrients in the soils. Their inability to be completely utilized leads to the accumulation of a high amount of mobile forms of nitrogen and phosphorus in the soils of the zoo's aviaries. A similar accumulation of these nutrients is characteristic of pasture soils after grazing (Sato et al., 2019; Tesfay et al., 2020). Differences in the content of nitrogen and phosphorus compounds in the soils of different parts of the zoo depend on the amount of their intake with excrement. A direct correlation dependence of the ammonium nitrogen content was revealed with animal excrement (r = 0.79 in May and 0.94 in August). This confirms the reason for the high concentrations of mobile nitrogen in the soil. A close dependence of the content of mobile phosphorus on the amount of excrement was found in August (r = 0.75).

Table 1. Impact of animals on the soil of the aviaries of the Rostov Zoo

No	Aviaries	Aviary area, m^2	The weight of animals on the aviary, kg m^{-2}	The amount of urine in the aviary, L $year^{-1}$ m^{-2}	Feces, kg year m^{-2}	Total animal waste, kg $year^{-1}$ m^{-2}
1	Birds (*Grus grus and others*)	1218	0.08	2.6	1.6	4.2
2	*Cervus elaphus*	1190	0.27	3.1	2.5	5.5
3	*Equus burchelli chapmani*	890	0.35	4.9	2.9	7.8
4	*Camelus bactrianus*	340	1.76	8.6	9.1	17.7
5	*Lama glama*	280	0.46	5.2	4.6	9.8
6	*Pseudois nayaur*	2300	0.23	1.1	1.6	2.7
7	*Equus donkeus asus*	2050	0.31	3.6	3.2	6.8
8	*Rhinocerotidaeus asusin*	1080	2.78	10.1	6.8	16.9
9	*Giraffa camelopardalis*	1390	0.43	2.9	2.6	5.5
10	*Bubalus arnee*	280	5.54	39.1	58.7	97.8

Bioindicators are often used as sensitive indicators of soil fertility under different land use systems and the degree of its degradation due to anthropogenic factors (Schwilch et al., 2016; Bünemann et al., 2018; Yertayeva et al., 2019). Biological diagnostics of soils is an important component of both local and global monitoring. Like other habitats, the soil is examined using various bioindicators. Microbial diversity and biochemical parameters are important indicators of soil condition, since they are involved in the decomposition of organic matter and the maintenance of sustainable soil function (Barrios, 2007; Akay and Sert, 2020). As a result of the studies, difference in the representation of bacteria of the Azotobacter genus has been established in soils of different plots of the Rostov Zoo. These bacteria play an important role in the nitrogen cycle, binding atmospheric nitrogen inaccessible to plants. Control sites were characterized by a high abundance of bacteria. Such values are characteristic of ordinary zonal chernozems (Kazeev et al., 2018). In aviaries and deer aviaries, no differences were found in the abundance of nitrogen-fixing bacteria of the Azotobacter genus compared with control sites. The minimal abundance of bacteria was in the soil of the aviary with zebras; the reduced abundance was in the soil of the aviary with bharals. The decrease in the abundance of bacteria was most likely due to the addition of sand into the soil of these aviaries. Sand is an inert material with minimal biological activity. Its addition into the soil leads to the "dilution" effect, reducing the number of microorganisms and biological activity. Aviaries with sand added to the soil showed the greatest variation in the values of the studied indicator as a result of different amounts of sand in soil samples.

Studies by various authors have established that the activity of soil enzymes can serve as an additional diagnostic indicator of soil fertility and its changes due to anthropogenic effects (Sinsabaugh et al., 2008; Burns et al., 2013; Raiesi and Kabiri, 2016). Much attention is drawn to the development of indicators of soil enzymes for use as a reliable indicator of soil fertility and health (Burns et al., 2013). However, despite extensive search, no single indicator has yet been found, that would allow us to draw a conclusion about the biological condition of the soil as a whole. In this paper, two classes of enzymes were used as bioindicators. From the hydrolases, the activity of urease was determined, and from the oxidoreductases, the activity of catalase and dehydrogenases was determined. Globally, Sinsabaugh et al. (2008) found that the activity of hydrolases is closely correlated to the content of organic matter in the soil, while the activity of oxidases is more susceptible to soil pH. This discovery showed that hydrolases may be more important for the decomposition of organic matter and, thus, affect nutrients and the carbon cycle. Enzymatic activity in the soil of the control site of the zoo is characterized by an average level of catalase activity during the entire observation period and varies slightly throughout all seasons. In soils of almost all aviaries, the activity of urease and dehydrogenases was significantly increased compared to the control values and varied greatly depending on the duration of observation (Figure 7).

Urease activity showed unusually high values in the soils of aviaries. This enzyme catalyzes the decomposition of urea, which enters the soil from animals in significant quantities every day. In aviaries with large animals, the flow of urine into the soil of aviaries amounts to several thousand liters per year. The correlation is detected between the animal load on the aviary soil cover and urease activity (r = 0.74). Unusually high values of urease activity have been established for the aviary with buffalo. Here, the excess of enzyme activity was 740% higher than in the soil of the control plot. This is due to the greatest pollution of the soil of this aviary, where several large animals live on a fairly small area. Urease activity was also 2-3 times higher in aviaries with deer, zebras and birds. A smaller increase is recorded in other aviaries. Only in one of the plots of the aviary with rhinoceros, a lower activity of urease was detected. This is due to two main reasons. The first is the short keeping period for rhinoceros in this aviary, which arrived at the zoo after a long break only a year and a half ago. The second reason was the addition of a significant amount of river sand used for amelioration of soil of the aviary. In this aviary, the soil surface is almost entirely covered with a layer of sand. Due to the use of sand to dilute the soil, enzyme activity was also relatively reduced in other aviaries (zebras, rams, giraffes). But still, the urease activity here was also higher than the control values.

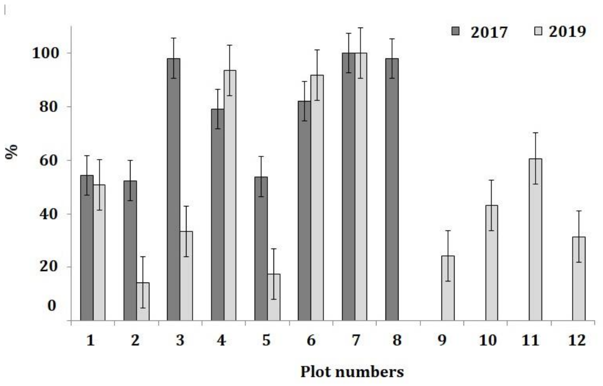

Figure 6. Changes in the structure of the soils of the zoo enclosures relative to the control values in different plots given in figure 1 according to control treatment.

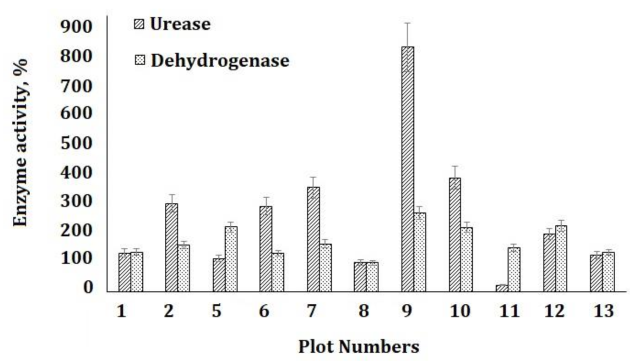

Figure 7. Changes in enzyme activities of the zoo soils in different plots given in figure 1 relative to the control site, May 2019.

The activity of dehydrogenases is associated with soil microorganisms (Kazeev et al., 2016). Its activity was also significantly increased in all observed areas relative to the control soil of the park. A large statistically significant ($p<0.01$) increase in enzyme activity was observed in the soils of aviaries with buffaloes (171%), giraffe (126%), sheep (123%) and camel (122%). In other sites, the increase ranged 32 to 65% relative to the control site ($p<0.05$). For this enzyme, such an increase in activity indicates the intensification of biological processes in the soils of animal aviaries. This is due to the increased flow of excess amounts of organic matter that serve as energy-yielding material for soil microflora. To quickly remove digestion products and metabolic waste, stimulation of the intensity of biological processes in soils is required. This will avoid the accumulation of organic waste that contribute to the associated issues of unpleasant odors and contamination of soil with pathogenic microflora.

Monitoring of the ecological condition of the aviaries of the Rostov Zoo showed a high degree of degradation of the physical properties of soils and their contamination with metabolic products of the kept animals. Possible negative effects of grazing on plant biomass and soil quality have been reported previously (Qasim et al., 2017; Hillenbrand et al., 2019; Sato et al., 2019). Keeping animals in the limited space of the zoo aviaries leads to soil compaction and a decrease in water permeability, which leads to stagnation of moisture on the surface, the formation of puddles and dirt in the conditions of heavy clay soil composition. One of the methods for soil amelioration is the technology used by the zoo designed to lighten the particle size distribution of soils using sand, which is added to the soil of some of the most degraded areas (aviaries with sheep, rhinoceros, buffalo, zebras, giraffe). The amount of added sand varies in different study plots. Under the conditions of low disturbance of the topsoil, sand is not applied at all, and in some aviaries with the largest animals (elephants, bisons), sand completely covers the soil with a thick layer, which makes monitoring the topsoil in these aviaries unproductive. Currently, studies are underway on the use of ameliorants and other substances: glauconite, wood chips and sawdust, acrylic-based hydrogel. The use of an acryl-containing hydrogel does not inhibit the heterotrophic soil microflora (Mellelo et al., 2019), which is important for maintaining a high decomposition rate of animal waste and, therefore, it may be used to regulate the water regime of soils. In addition, biologically active substances can be used to increase the rate of biodegradation of organic substances in zoo soils. For example, humic substances and preparations based on them can significantly increase the biological activity of soils (Stankevica et al., 2019).

Keeping animals in aviaries can lead not only to soil degradation, but also to air pollution with ammonia. It's can be produced not only by farm animals (Priekulis et al., 2019), but also, locally, by zoo animals. Therefore, it is important to optimize the nitrogen cycle in soils, for which it is important to maintain a high rate of biological processes in the soil and, in particular, nitrification.

In general, soils of Rostov zoo have a high biological activity comparable to the soils of natural ecosystems. This contributes to the biodestruction of a significant proportion of organic matter entering the zoo soil. The amount of animal excrements in some of the zoo aviaries is much higher than in natural ecosystems. And it continues to be so for decades. Increasing the speed of biological processes in the zoo soils is necessary for accelerated mineralization of organic pollutants and suppression of pathogenic microflora. Low biological activity of soils can lead to a decrease in the rate of biodegradation of organic substances and other negative processes (Yurkova et al., 2009). Therefore, work is currently underway to replace the main ameliorant used to improve the physical properties of soils. River sand used for this purpose in some aviaries with large animals, reduces the humus content and biological activity of soils.

Conclusion

The soils of the Rostov Zoo are subject to degradation disturbances as a result of keeping animals in aviaries, as well as the recreational impact of visitors. The difference in the ecological properties of soils at different monitoring sites of the zoo has been established. Large ungulate animals have a maximum effect on the physical properties of soils. This is especially true for deer, buffalo and zebras, which have a higher destructive effect on the soil surface compared to other animals. Minimal disturbances are showed in aviaries. Even large emus almost do not disturb the physical properties of soils. The addition of sand as an ameliorant to improve the water-physical properties of soils in aviaries with mountain sheep, zebras, rhinoceros and giraffe leads to significant changes in the physical and biological properties of soils. Biological activity is significantly reduced as a result of dilution of the soil with inert material. The most informative indicators of the ecological condition of the soils of the Rostov Zoo were the density and structure of soils. Soil enzymes, especially urease, were good bioindicators of soil contamination with animal waste products. The abundance of nitrogen-fixing bacteria, the reaction of the medium, the content of highly soluble salts, soil temperature and humidity were less informative indicators for assessing the ecological status of zoo soils.

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References

Akay, A., Sert, D., 2020. The effects of whey application on the soil biological properties and plant growth. *Eurasian Journal of Soil Science* 9(4): 349-355.

AZA, 2016. Association of Zoos and Aquariums. Available at [Access date: 17.09.2016]: https://www.aza.org/

Barrios, E., 2007. Soil biota, ecosystem services and land productivity. *Ecological Economics* 64(2): 269-285.

Bezuglova, O.S., Tagiverdiev, S.S., Gorbov, S.N., 2018. Physical properties of urban soils in Rostov agglomeration. *Eurasian Soil Science* 51(9): 1105-1110.

Bünemann, E.K., Bongiorno, G., Bai, Z., Creamer, R.E., De Deyn, G., Goede, R., Fleskens, L., Geissen, V., Kuyper, T.W., Mäder, P., Pulleman, M., Sukkel, W., van Groenigen, J.W., Brussaard, L. 2018. Soil quality – A critical review. *Soil Biology and Biochemistry* 120: 105-125.

Burns, R.G., DeForest, J.L., Jürgen, M., Sinsabaugh, R.L., Stromberger, M.E., Wallenstein, M.D., Weintraub, M.N., Zoppini, A., 2013. Soil enzymes in a changing environment: Current knowledge and future directions. *Soil Biology and Biochemistry* 58: 216-234.

Buzmakov, S.A., Kostyleva, N.V., Sorokina, T.V. 2014. About an assessment of emissions of atmosphere from future Perm zoo. *Geographical Bulletin* 4 (31): 67-74.

Conrad, C.C., Stanford, K., Narvaez-Bravo, C., Neumann, N.F., Munns, K., Tymensen, L., Jokinen, C., McAllister, T.A., 2018. Zoonotic fecal pathogens and antimicrobial resistance in canadian petting zoos. *Microorganisms* 6(3): 70.

Gorbov, S.N., Bezuglova, O.S., 2014. Specific features of organic matter in urban soils of Rostov-on-Don. *Eurasian Soil Science* 47 (8): 792-800.

Gorbov, S.N., Bezuglova, O.S., Varduni, T.V., Gorovtsov, A.V., Tagiverdiev, S.S., Hildebrant, Y.A., 2015. Genotoxicity and contamination of natural and anthropogenically transformed soils of the city of Rostov-on-Don with heavy metals. *Eurasian Soil Science* 48(12): 1383-1392.

Gustin, P.N., Kelley, D.C., 1971. A survey of zoo aviaries for the presence of Histoplasma capsulatum and Cryptococcus neoformans. *Mycopathologia et mycologia applicata* 45(2): 93-102.

Hillenbrand, M., Thompson, R., Wang, F., Apfelbaum, S., Teagu, R., 2019. Impacts of holistic planned grazing with bison compared to continuous grazing with cattle in South Dakota shortgrass prairie. *Agriculture, Ecosystems & Environment* 279: 156-168.

Ivashchenko, K., Ananyeva, N., Vasenev, V., Sushko, S., Seleznyov, A., Kudeyarov, V., 2019. Microbial C-availability and organic matter decomposition in urban soils of megapolis depend on functional zoning. *Soil & Environment* 38(1): 31-41.

Karlen, D.L., Veum, K.S., Sudduth, K.A., Obrycki, J.F., Nunes, M.R. 2019. Soil Health assessment: Past accomplishments, current activities, and future opportunities. *Soil and Tillage Research* 195: 104365.

Kazeev, K.S., Kozun, Y.S., Kolesnikov, S.I., 2015. Applying an integral index to evaluate the spatial differentiation of biological properties of soils along an aridity gradient in the south of Russia. *Contemporary Problems of Ecology* 8 (1): 91-98.

Kazeev, K.S., Kutrovskii, M.A., Dadenko, E.V., Kolesnikov, S.I., Val'kov, V.F., 2012. The influence of carbonates in parent rocks on the biological properties of mountain soils of the Northwest Caucasus region. *Eurasian Soil Science* 45(3): 282-289.

Kazeev, K.Sh., Kolesnikov, S.I., Akimenko, Yu.V., Dadenko, E.V., 2016. Methods of bio-diagnostics of terrestrial ecosystems. Southern Federal University. Rostov-on-Don, Russia. 356p. [In Russian].

Kazeev, K.Sh., Odabashian, M.Yu., Trushkov, A.V., Kolesnikov, S.I., 2020. Assessment of the influence of pyrogenic factors on the biological properties of chernozems. *Eurasian Soil Science* 53(11): 1610-1619.

Kazeev, K.Sh., Zhadobin, A.V., Barbashev, A.I., Akimenko, Yu.V., Kolesnikov, S.I., 2018. Ecological state of the soil at the Rostov-on-Don zoo. 18th International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology (SGEM). Conference Proceedings 18: 119-126.

Kolesnikov, S.I., Timoshenko, A.N., Kazeev, K.S., Akimenko, Y.V., Soldatov, A.V., 2019. Comparison of ecotoxicity of nickel and iron oxides and their nanoforms. *Rasayan Journal of Chemistry* 12(2): 549-553.

Kuznetsov V.A., Ryzhova I.M., Stoma G.V. 2019. Transformation of forest ecosystems in Moscow megapolis under recreational impacts. *Eurasian Soil Science* 52(5): 584-592.

Martinez-Mera, E., Torregroza, A.C., Garcia, A.V., Geronimo, L.R., 2017. Relationship between soil physicochemical characteristics and nitrogen-fixing bacteria in agricultural soils of the Atlántico department, Colombia. *Soil & Environment* 36(2): 174-181.

Mellelo, E., Samuilova, E.O., Denisov, T.S., Martynova, D.M., Olekhnovich, R.O., 2019. Influence of the bentonite-containing acrylic humectant composite on the soil microflora. *Agronomy Research* 17(4): 1960-1968.

Momirović, N., Kadović, R., Perović, V., Marjanović, M., Baumgertel, A., 2019. Spatial assessment of the areas sensitive to degradation in the rural area of the municipality Čukarica. *International Soil and Water Conservation Research* 7(1): 71-80.

Priekulis, J., Melece, L., Laurs, A., 2019. Most appropriate measures for reducing ammonia emissions in Latvia's pig and poultry housing. *Agronomy Research* 17(3): 797-805.

Qasim, S., Gul, S., Hussain, M., Fayyaz, S., Sarfraz, H., Gulbano A., Muhammad, R., Syed, Y., Shah, Q., 2017. Influence of grazing exclosure on vegetation biomass and soil quality. *International Soil and Water Conservation Research* 5(1): 62-68.

Raiesi, F., Kabiri, V., 2016. Identification of soil quality indicators for assessing the effect of different tillage practices through a soil quality index in a semi-arid environment. *Ecological Indicators* 71: 198-207.

Sato, C.F., Strong, C.L., Holliday, P., Florance, D., Pierson, J., Lindenmayer, D.B., 2019. Environmental and grazing management drivers of soil condition. *Agriculture, Ecosystems & Environment* 276: 1-7.

Schwilch, G., Bernet, L., Fleskens, L., Giannakis, E., Leventon, J., Maranon, T., Mills, J., Short, C., Stolte, J., van Delden, H., Verzandvoort, S., 2016. Operationalizing ecosystem services for the mitigation of soil threats: a proposed framework. *Ecological Indicators* 67: 586-597.

Sinsabaugh, R.L., Lauber, C.L., Weintraub, M.N., Ahmed, B., Allison, S.D., Crenshaw, C., Contosta, A.R., Cusack, D., Frey, S., Gallo, M.E., Gartner, T.B., Hobbie, S.E., Holland, K., Keeler, B.L., Powers, J.S., Stursova, M., Takacs-Vesbach, C., Waldrop, M.P., Wallenstein, M.D., Zak, D.R., Zeglin, L.H., 2008. Stoichiometry of soil enzyme activity at global scale. Ecology Letters 11(11): 1252-1264.

Stankevica, K., Vincevica-Gaile, Z., Klavins, M. 2019. Role of humic substances in agriculture and variability of their content in freshwater lake sapropel. *Agronomy Research* 17(3): 850-861.

Tao, X., Cui, J., Dai, Y., Wang, Z., Xu, X., 2016. Soil respiration responses to soil physiochemical properties in urban different green-lands: A case study in Hefei, China. *International Soil and Water Conservation Research* 4(3): 224-229.

Tesfay, F., Kibret, K., Gebrekirstos, A., Hadigu, K.M., 2020. Changes in selected soil properties across a chronosequence of exclosures in the central dry lowlands of Ethiopia. *Eurasian Journal of Soil Science* 9(2): 173-185.

Yertayeva, Z., Kızılkaya, R., Kaldybayev, S., Seitkali, N., Abdraimova, N., Zhamangarayeva, A.i 2019. Changes in biological soil quality indicators under saline soil condition after amelioration with alfalfa (Medicago sativa L.) cultivation in meadow Solonchak. *Eurasian Journal of Soil Science* 8(3): 189-195.

Yurkova, N.E., Yurkov, A.M., Smagin, A.V., 2009. Ecological status of soils in Moscow Zoo. *Eurasian Soil Science* 42(3): 342-348.