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Assessment of the Condition of Pine Plantations in the Area of Influence of Municipal Waste Landfills on the Example of the Zhytomyr Landfill, Ukraine

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ABSTRACT

The paper presents the results of the research conducted to assess the degree of transformation of forest ecosystems in the area of influence of the Zhytomyr landfill (Ukraine) – one of the typical Ukrainian landfills, which is operated with minimal implementation of environmental protection measures. The study was conducted to identify the relationship between the condition of plantations and the functioning of municipal solid waste landfills. In the study involving estimating the transformation degree of the forest ecosystems in the area of influence of the municipal solid waste landfill in Zhytomyr, it was established that in the studied areas there was a decrease in bonitation by I-II classes, completeness by 0.1–0.2 units, and growth by 13–35%, in comparison with the background values. On the basis of the research of the condition of pine plantations by categories of vital activity of trees, the integral indicator was calculated – the index of the condition of forest stands, which characterizes the degree of their damage in the event of aerial pollution of soil and groundwater. It was determined that the maximum values of the index of forest stands condition were observed in the area closest to the landfill (2.88 units), i.e, these are severely weakened stands, the minimum in the control (1.28). On the basis of the obtained results, it was established that Scots pine is a convenient and acceptable bioindicator for assessing the state of the environment in the area of influence of municipal landfills provided that its distribution is uniform on the territory and it is available for research. The sanitary condition of pine plantations deteriorates with the approach to the source of pollution. According to the established indices of the condition of pine plantations, a regression analysis was performed and a mathematical dependence was determined, which most accurately describes the change of these indicators with the distance from the landfill boundary. The approach used for the bioindication studies of conifers can be recommended for implementation in practice as a method for assessing the transformation of the environment in the area of influence of municipal solid waste landfills.

Keywords: landfill, bioindication, coniferous forests, Scots pine (*Pinus sylvestris* L.), index of forest stand condition.

INTRODUCTION

Landfills are the world's most common way of disposing of municipal solid waste. Landfilling entails a number of ecological risks (Skyba et al., 2020) as well as affects the environment and human health (Vaverková et al., 2019). Ukraine is in the process of harmonizing national legislation in the field of solid waste management with European standards. However, mixed collection and disposal (> 90%) remains a typical waste management scheme in Ukraine.

The vast majority of municipal waste is stored in landfills, spontaneous or specially organized. Most of the landfills in Ukraine today are already located within the urban territory, occupy significant areas and are called solid waste landfills (however, their facilities and operating conditions do not meet the regulatory requirements and are environmentally hazardous). About 1600 km^2 of land in Ukraine is occupied by waste (one of the highest rates of waste accumulation in the world); today, there are more than 2000 facilities in the country that were organized without projects and engineering and hydrogeological surveys.

The result has been a significant number of environmental problems, including groundwater pollution by leachate (by infiltration of contaminated water into groundwater aquifers) and the migration of pollutants along with underground, surface and aboveground streams (Osipova & Remez 2015; Vambol et al., 2017). The infiltration of leachates into surface and groundwater causes their contamination by heavy metals (Kostenko et al., 2017, Sakalova et al., 2019 a), ammonium ions (Sakalova et al., 2019 b), as well as eutrophication of reservoirs (Nykyforov et al., 2016). Free entry of landfill gas into the environment causes a number of negative consequences; in particular, it leads to air pollution of the surrounding areas with toxic compounds (Stalinska 2016; Safranov et al., 2016).

As the garbage mass is characterized by developed porosity and content of organic components, conditions are created for the active development of microbiological processes. Studies have shown that a significant part of various organic and inorganic compounds, the emission of which into the atmosphere exceeds the permissible standards, is recorded at MSW landfills. High concentrations of ammonia – up to 1.19 mg / m^3, which is 30 MPC for settlements, were found in the air on the landfill territory in the area of fresh waste storage. On the territory of landfills, there are centers of smoldering or active combustion. The analysis of the air in the smoldering area of the landfill shows the content of such toxic components as: methane, carbon monoxide (up to 2 MPC), ammonia (11 MPC), phenatrene, and anthracene. In the case of solid waste combustion, the concentrations of toxic components increase tens and hundreds of times, while significantly expanding the list of toxic and explosive gases. In particular, the following substances were recorded in the air in the combustion area of the landfill: carbon monoxide (49 - 150 MPC), sulfur oxide (40 - 200 MPC), nitric oxide (up to 50 MPC), methane, ammonia (9 MPC), benzene (42 MPC), fluorene, phenanthrene, anthracene, ethane, ethylene, propane, propylene, and norm-butane. A number of organic compounds of the class of phenols, substituted naphthalenes, substituted phenatrenes, aliphatic and aromatic hydrocarbons have also been identified in the selected air samples (Korbut, 2015).

The location of landfills is often planned without taking into account possible ecological risks in terms of impact on certain environmental objects, or (in the case of spontaneous landfills) – not planned at all (Yazdani et al., 2015).

Studies show that MSW landfills create a very specific environment and affect vegetation, emphasizing the need for their constant monitoring (Vaverková et al., 2019). Landfills are often located near forests and affect their condition, resulting in degradation of forest areas (Lamasanu et al., 2012). Such a location of landfills makes it possible to carry out bioindication monitoring (Manning & Feder, 1985; Badtiyev & Kulemin, 2001) and, in the future, to obtain an integral assessment of the state of the environment in the influence area of such objects. In contrast to the physicochemical approach, which does not provide a comprehensive picture of the state of the environment and, moreover, the impact of this environment on biological systems, the bioindication assessment methods are integral and allow a comprehensive assessment of the state of the environment. Living indicators under conditions of chronic anthropogenic loads react even to relatively weak impacts due to the cumulative effect, and sum up the influence of all biologically important impacts.

The response of forest ecosystems to unfavorable environmental conditions is manifested in the damage of the structure and functions of the entire system and its individual components. These damages can be recorded by a number of signs observed during a careful analysis of a natural object. The most common signs of damage in the state of the forest ecosystem are: the appearance of dead wood and weakened trees among the dominating species; a decrease (noticeable) in the size of needles and leaves during the year in which observations are carried out in comparison with previous years; premature (long before autumn) yellowing and leaf fall; slowing down the growth of trees in height and

diameter; the appearance of chlorosis and necrosis of needles and leaves, a reduction in the lifespan of needles; a noticeable increase in damage to trees by diseases and entomopests (fungi and insects); loss of tubular fungi (macromycetes) from the forest community and a decrease in the species composition and number of lamellar fungi; a decrease in the species composition and occurence of the main species of epiphytic lichens (which live on tree trunks) and a decrease in the coverage of the area of tree trunks with lichens.

These signs can be recorded without the use of special devices and scientific equipment. However, in order to notice them and assess the degree of danger, it is necessary to have a starting point, the «background» state of the ecosystem in a clearly undisturbed area of forest. Coniferous trees very often serve as indicators of various types of pollutants. Their use allows for bioindication in territories of different area and obtaining the information on the state of the environment in urban ecosystems of different ranks and character. It is believed that pine forests are most sensitive to air pollution. (Livkovych & Muzh, 2018). Scots pine (*Pinus sylvestris* L.) is the main forest-forming species in the Ukrainian Polissya (about 35% of the state forest fund of Ukraine) and is very sensitive to the changes in environmental conditions (Melnyk, 2019).

This determines the choice of pine as an indicator of anthropogenic impact, currently accepted as a «standard of biodiagnostics». Pine sensitively reacts to a slightest change in growth conditions, including environmental pollution, is widespread, and has priority over deciduous species due to the possibility of year-round observations (Deynega & Savvateyeva, 2012).

The main signs of damage to conifers as a result of air pollution:

- dry apex – characteristic damage to conifers by high concentrations of gases and, first of all, by sulfur dioxide;
- distal necrosis – cessation of growth of needles and branches under the influence of nitrogen dioxide, ammonia, ethylene and ozone;
- chlorosis – early aging of needles under the influence of fluorides, heavy metals and acid rain.

The aim of the study was to assess the condition of pine stands in the area of influence of the MSW landfill in Zhytomyr (Ukraine), and to zone the area of landfill influence with the prospect of further assessment of the atmospheric air condition on the basis of the obtained data.

MATERIALS AND METHODS

The object of the study was the MSW landfill in the city of Zhytomyr (Ukraine) – a typical Ukrainian landfill, which is operated with minimal implementation of environmental protection measures. All municipal waste of the city of Zhytomyr is disposed here without any preliminary sorting. The municipal solid waste landfill has been in operation since 1957, with a total area of 216,000 m^2; storage area – 187,000 m^2. Its proximity to the nearest settlement is 514 m (Fig. 1). The landfill has long been overloaded and is a source of intense pollution of the atmosphere and groundwater.

The geographical location of the Zhytomyr solid waste landfill is quite specific and allows for various comprehensive studies: on the western

Figure 1. View of the municipal landfill for solid waste disposal (https://www.google.com/maps)

Figure 2. Visualization of the geographical location of the solid waste landfill in the city of Zhytomyr (Ukraine), (https://www.google.com/maps)

side of the landfill site (according to the sanitary passport of the landfill), at a distance of 0.05 km, there is a coniferous forest (Fig. 2). The forest area is about 1,000,000 km^2 (the shape of the plot can be described as a parallelogram with sides of 750 and 1400 meters). On all other sides, the forest is surrounded by country estates without large highways and industrial enterprises, which could distort the picture of the study and further affect the condition of forest plantations.

The test areas for studying the state of forest ecosystems in the zone of influence of the solid waste landfill were established according to the methods generally accepted in forestry and forest taxation (industry-specific standard OST 566983) under typical growing conditions, in tree stands that are homogeneous in their taxation parameters (Anuchyn, 1982). The size of the test areas was taken so that the number of trees on them was about 200. The research was based on the classical method of comparative forest ecology with its detailing in some ecological and forestry areas. On the test areas, a continuous inventory of forest stands was carried out, and the taxation indicators of plantations were determined. The assessment of the plantings bonitet was carried out using the scale of M.M. Orlov. A control test plot was established in the residential area.

The trees were described in detail according to the method of (Vorobyov, 1953), indicating the location of the plot, relief, ground cover, growing conditions, composition, age, and origin of the stand. In order to determine the taxonomic indices of plantations, the height of each tree was measured, and its diameter at a height of 1.3 m. The average height was determined graphically (Antonovskyy et al., 1979), whereas the class of bonitet and completeness of the stand was determined according to the "Tables of growth and marketability of tree plantations of Ukraine", 1969. The total stock of wood on the test areas was established according to the assortment tables by (Mikitin, 1984).

Table 1. The degree of damage to forests

No.	Category	Description
I	Healthy	Trees without external symptoms of damage. The crown is pointed or blunt-topped on middle-aged and older trees. The growth of the current year is normal for this species, age and growing conditions. The needles are of normal color and size with a life span of at least 3 years.
II	Weakened	Trees, that have up to 1/3 of their needles damaged (necrosis, chlorosis) or shed. The crown is openwork. Young trees are sharp-topped, midle-aged and older trees are blunt-topped. The needles are normal or slightly shortened with a life span of 2-3 years. The growth is shortened by no more than 1/2 of normal; there is drying of individual branches.This category also includes trees that do not have external signs of damage to needles or shoots, but are marked by local mechanical damage or damage of the trunk or root branches by fungal pathogens.
III	Severely weakened trees	From 1/3 to 2/3 of the needles are damaged or shed. The growth of needles and shoots is severely inhibited. The crown is very openwork. Young trees are blunt-topped, midle-aged and older trees are flat-topped. The needles have a chlorotic color and a lifespan of less than 2 years. The dry top does not exceed 2/3 of the crown. Damage to the root branches or trunk up to 2/3 of the perimeter. In some places, colonization of stem pests and other signs of the activity of wood-destroying fungi are observed.
IV	Drying	Trees that have more than 2/3 of the needles damaged or shed. The growth of needles and shoots is severely inhibited. Needles are with severe chlorosis or yellowish. Their life span is about a year. The crown is dry-topped, more than 2/3 of it is dried. Damage to the trunk and root branches is more than 2/3 of the perimeter. There are signs of infestation by stem pests.
V	Fresh dead wood	Trees that have withered in the current year, are inhabited or worked by stem pests. The needles are gray, yellow or reddish-brown.
VI	Dry deadwood	Trees that have withered in previous years. The needles are shed. Bark and small branches are partially or completely absent. The bark peels off, under it there is mycelium of wood-destroying fungi.

In the process of assessing the condition of plantations, the tree damage was determined according to the (Sanitary Rules in the Forests of Ukraine, 1995) with a supplement for pine, developed by the Ecology Laboratory of Ukrainian Research Institute of Forestry and Forest Melioration named after H. M. Vysotsky "Methodical recommendations for the diagnosis and zoning of damage to forests of Ukraine by agronomic pollution" (2002), which take into account the shape of the crown and the life span of the needles.

The main aim of the study was to identify the relationship between the sanitary condition of plantations and the functioning of municipal solid waste landfill.

RESULTS AND DISCUSSION

In the study of the estimation of the transformation degree of forest ecosystems in the area of influence of the municipal solid waste landfill in Zhytomyr, it was established that in the studied areas there was a decrease in bonitet by I-II classes, completeness by 0.1-0.2 units, and growth by 13-35% in comparison with the background values. According to the methodology of the Ukrainian Research Institute of Forestry and Forest Melioration named after H. M. Vysotsky, the sanitary condition of each tree on a 6-point scale was determined with subsequent estimation of the average index of sanitary condition of the plantation, which was calculated by the formula (1).

Determining the condition of pine plantations by categories of tree life, allowed calculating an integrated indicator – the index of forest stands condition (*Ic*), which characterizes the degree of damage in the event of aeral pollution of soils and groundwater.

$$Ic = \frac{n1 + 2\,n2 + 3n3 + 4n4 + 5n5 + 6n6}{n1 + n2 + n3 + n4 + n5 + n6} \quad (1)$$

where: *n1, n2, ..., n6* – the number of trees of the corresponding category of sanitary condition.

Indices of the condition of plantations provide an opportunity to comprehensively assess the condition of trees in the study area: 1.0–1.50 – healthy; 1.51–2.50 – weakened; 2.51–3.50 – severely weakened; 3.51–4.50 – drying; 4.51–6.00 – dry.

Statistical data processing was performed using correlation and regression analyses. In the process of summarizing the data on the condition of forest plantations in the area of the solid waste landfill, it was determined (Table 2) that throughout the entire observation period, the maximum values of Ic of forest stands were noted in the area closest to the landfill (3.00 units), i.e., these are severely weakened stands, the minimum in the control (1.28).

Beyond the distance of 500 meters, no research was conducted, because at this distance we approach to the country estate, and therefore the impact on the condition of trees is due not only to the functioning of the landfill, but also human negligence.

According to the established indices of the condition of pine plantations, a regression analysis was performed and a mathematical dependence was determined, which most accurately describes the change of these indicators with the distance from the landfill boundary (Fig. 3).

Thus, the change in the indices of condition (*Ic*) of pine plantations at a distance from the landfill is polynomial in nature and is described by the dependence:

$$y = -4E-06x^2 - 0.001x + 3.0129 \qquad R^2 = 0.9886 \quad (2)$$

The correctness of the obtained mathematical dependence is confirmed by the high value of the reliability, the approximation is 0.9886.

Table 2. The results of the Ic calculation and estimation of the sanitary condition of plantations

Distance from the landfill, m	Number of trees studied	Category of sanitary condition						Index of sanitary condition	Sanitary condition of plantations
		I	II	III	IV	V	VI		
0	200	4	62	89	27	11	7	3.00	severely weakened
100	200	11	76	67	28	8	10	2.88	severely weakened
200	200	16	89	65	18	7	5	2.63	severely weakened
300	200	33	102	44	12	5	4	2.40	weakened
400	200	81	91	17	7	2	2	1.82	weakened
500	200	114	77	6	1	2	-	1.50	healthy

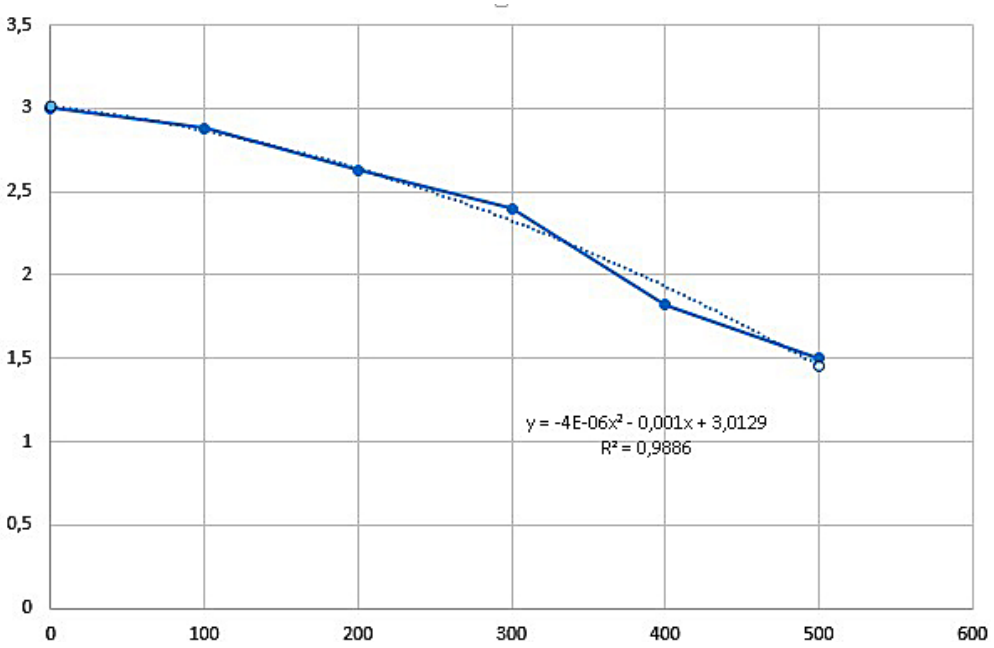

Figure 3. Index of the condition (Ic) of pine plantations at different distances from the landfill

Assessement of the impact of the landfill on the environment with the help of Scots pine allows characterizing the impact on the environment over a long period of time. This, to some extent, determined the type of obtained (polynomial) dependence. Because when the weather conditions change (first of all, with the change of the direction of the wind and the decrease of its strength), the area of influence of the landfill decreases. Thus, pines that grow over long distances may not be suppressed, or may be less so. During such periods, pollutants do not spread over long distances and are localized in a smaller area, significantly closer to the landfill boundary.

That is why the values of the condition indices of pine plantations are consistently slightly higher when approaching the landfill boundary, and the jump in values is observed after a distance of 300 meters.

CONCLUSIONS

According to the results of the research, it was established that Scots pine is a convenient and acceptable bioindicator for assessing the state of the environment in the area of municipal waste landfills, provided that its distribution is uniform on the territory and it is available for research. The sanitary condition of pine plantations deteriorates with the approach to the source of pollution. The long-term impact of the landfill causes the suppression of forest ecosystems in the area adjacent to the landfill, which has significantly reduced its ability to homeostasis compared to forest ecosystems that are not disturbed by technogenesis. The index of the condition of pine plantations changes more than twice compared to the control. According to the established indices of the condition of pine plantations, a regression analysis was performed and a mathematical dependence was determined, which most accurately describes the change of these indicators with the distance from the landfill boundary. The approach used for bioindication studies of conifers can be recommended for implementation in practice as a method for assessing the transformation of the environment in the area of influence of municipal solid waste landfills.

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