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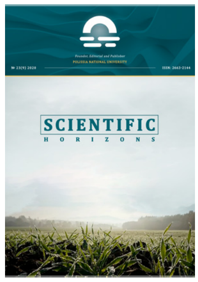

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The bioindicative characteristics of the *Betula pendula Roth* species in the dendrocenoses of the solid household waste landfill's influence zone

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Abstract. Due to the constant inflow of toxic substances into the air, soil, and groundwater, landfills not only physically occupy huge expanses of land but also have an increasing negative impact on the ecosystem and its constituent parts. As such, the research relevance is determined by the problem of landfill expansion as well as the size in Ukraine getting worse by the minute. An example of morphometric alterations in leaf indicators of the species Betula pendula Roth is used to assess the effects of the municipal solid waste landfill in Zhytomyr on the nearby dendrocenoses. The

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most revealing morphometric indications were identified by examining the dimensions and characteristics of the venation of leaf plates at various distances from the dump up to a radius of one kilometre. Moreover, the length of the leaf's second vein of the second order was determined as the most stable parameter, while the difference in the lengths between the bases of the first and second veins of the second order was the most sensitive. Based on the data collected on the varying asymmetry of the leaf plates, it is concluded that variations exist in the morphometric indicators over the entire distance under investigation. These variations enable the determination of the environment within the range of "polluted" to "excessively polluted". These findings can serve as a quick way to gauge how much of an influence landfills have on the ecosystems around them when sanitary protection strips are established, municipal waste dumps are built and outfitted, etc

Keywords: veining; morphometric indications; birch; pollution; waste

INTRODUCTION

Landfills are an urgent problem nowadays, and the number of them is increasing annually. One of the primary causes of pollution in the environment is spontaneous landfills. Due to incorrect functioning, current landfills are in unsatisfactory condition. Landfills are gradually engulfing plantations, streams, and woods. Due to the lack of storage places, perimeter collapse, and conditions of the organization, garbage is frequently dispersed. The contamination that these landfills filter into the subterranean aquifer and incorporate into the cycles of chemicals has a detrimental effect on the health of the nearby ecosystems and, as a result, plant, and animal organisms. When solid household waste breaks down or burns, dangerous and occasionally cancer-causing chemicals are released into the atmosphere. The condition of ecosystems' permanent components has the biggest impact on all these factors. As a result, these ecosystem components serve as the most useful indicators of the ecological health of ecosystems.

The functioning of human society is related to environmental pollution. Forests, which act as natural cleaners and sorbents of pollution, play a special role in these processes. A significant proportion of pollutants settle and later accumulate in the phytomass of woody plants. In general, temperature, chemical pollution, and population density are known stressors to populations in ecosystems (Benítez *et al.,* 2020). Trees clean, moisturize, and enrich the atmosphere of cities with oxygen, influence radiation levels and temperature, and reduce wind impact and noise pollution (Pfeifer *et al.,* 2022). Sanitary-hygienic, architectural, economic, and other human activities severely impact green spaces. One of the types of extreme conditions of vegetation habitats is landfills (Vaverková *et al.,* 2019).

The situation that has developed around the landfill of solid household waste (Zhytomyr, Ukraine) has recently caused considerable concern. The low level of use of waste processing causes its accumulation in the surrounding natural environment and pollution. Hundreds of thousands of tons of household waste accumulate in city landfills every year. The location, arrangement, and operating conditions of most waste disposal sites do not meet regulatory requirements, which increases the environmental hazard of these facilities. A large landfill borders 6 blocks of the forest of the State Enterprise "Zhytomyrske LG". The influence of waste and the gas composition of the air in landfills is reflected in the form of various anomalies in the development of dendrocenoses in adjacent landscapes (Skydan *et al.,* 2022).

Many studies state that there are many species of plants and animals in ecosystems that are the first to respond to the appearance or increase of anthropogenic influence in the form of pollution (Orlov *et al.,* 2023; Fedoniuk & Skydan, 2023). Dendrocenoses, in their majority, actively respond to technogenic load by changing their growth and development indicators. For example, Y. Petrushkevych and I. Korshykov (2020) noted a clear trend regarding the differences in the responses of plants from a relatively clean area and polluted areas: in control trees, the coefficient of variation was higher for the right half of the leaf (right-sided asymmetry), and in man-made area plants, a small left-sided asymmetry was present (Fedoniuk *et al.,* 2022). The reactions of plants in response to pollution vary greatly, from colour changes to changes in the size and shape of leaf plates, leaf asymmetry, crown asymmetry, etc.

L. Romanchuk *et al.* (2018) noted, that many woody plants with pronounced and easily visible responses to environmental pollution are often used as indicator plants that allow not only determining the fact of the presence of pollution but also characterizing their scale and origin. K. Hartikainen *et al.* (2020) noted that even a slight but realistic increase in environmental temperature can significantly change the structure of silver birch leaves. The effect of changes in the gas composition (emissions of biogenic volatile organic compounds) on the morphometric indicators of the Betula species was noted by F. Ndah *et al.* (2022). As a result, such species either disappear from such ecosystems or react in the form of morphological or physiological disturbances. In conditions of prolonged impact of an undesirable object, the search for contamination signs becomes difficult since some of the sensitive species could have already disappeared under the influence of adverse conditions. In this case, species that respond to the presence of adverse factors in the environment in the form of morphological disturbances come to the fore, as can be successfully recorded.

As a bioindicator of the quality of the environment, the hanging birch has been used successfully for quite some time (*Betula pendula*) in research of M. Aničić Urošević *et al.* (2019) and M. Bożym *et al.* (2021). They noticed that it is massive and widespread and is part of various biotopes (ecosystems); its area includes steppe and forest-steppe zones in Scandinavia, Central and Atlantic Europe, the Mediterranean, and the Balkans. Several questions regarding the use of birch as a bioindicator remain unanswered. There is insufficient information on the disturbance of development stability on the ecological periphery of the area. The regularities of the spatial distribution of the asymmetry coefficient of this type have not been studied. However, M. Vaverková *et al.* (2019) confirmed the possibility of determining environmental pollution under the influence of solid waste landfills by biotesting methods. This study demonstrated and proved the possibility of using hanging birch populations (*Betula péndula*), oak (*Quercus robur* L.), and alder (*Alnus glutinosa* (L.) Gaertn.) to assess the impact of landfills on the environment.

As such, the study aimed to analyse the ecological condition of trees in the dendrocenoses of the forest, which are developing in the area of the municipal solid waste landfill (MSW).

MATERIALS AND METHODS

Characteristics of the research object. The municipal solid waste dump in Zhytomyr city is situated 0.65 km from the city limits; 0.514 km from residential and public buildings; 0.05 km from agricultural land; 65-70-0.05 km from the State Enterprise "Zhytomyrske LG" forest massif; and 1200 m from the Kroshenka River, which is a left tributary of the Kamianka River, which is a left tributary of the Teteriv River (Fig. 1). The primary data source for this project was created using the "Dynamic World V1" product on the Google Earth Engin platform (n.d.).

Figure 1. *Map scheme of the location of the municipal solid waste dump in Zhytomyr (blocks 65-70 of the forest lands of the State Enterprise "Zhytomyr LH") and the investigated forest ecosystems*
Source: *Google Earth Engin platform (n.d.)*

Collecting plant material peculiarities. To investigate the effects of the Zhytomyr landfill on dendrocenoses, measurements were made of a hanging birch leaf's dimension. The investigated area was separated into groups according to varying distances from the solid waste border (0-99, 100-199, 200-299, 300-399, 400-499, 500-599, 600-699, 700-799, 800-899, 900-1000 m). A location inside a forest massif that was no closer than two kilometres to the closest highway (hydropark) was selected as the control area. Ten birch trees yielded ten leaves each. This resulted in a total of 100 leaves in each experimental region, sufficient for appropriate correlation analysis and statistical analysis of a small sample of values. Regarding measuring indications, the degree of plant asymmetry was considered from both the left and right sides concerning the two sides. The average relative difference for one attribute for each leaf is a crucial measure of development stability for a collection of traits. This was accomplished by measuring and determining each chosen leaf's curve. There was no discernible variation in the leaf tip's curvature in the studied sites. As a result, this parameter was ignored in the subsequent investigation. The material collection started following the conclusion of the time of intense leaf growth, which typically falls between late May and early June throughout the years 2020-2022.

Leaves were sampled for each interval from medieval woody plants by the route (tape transect) method (Loya, 1978). 100 leaves were measured to assess the ecological state of large areas. In the case of damage, another +10% was collected. The leaves were taken from the lower part of the crown, at the level of the raised hand, from the maximum number of available branches (at the same time, they tried to use parts of the plant located in different directions, conditionally to the north, south, west, and east) (Fig. 2).

Figure 2. *Leaf collection sites*
Source: *compiled by the authors*

Birch leaves were used only from shortened shoots. About one leaf, the average size for this species, was selected. Damaged leaves were used in the study only if the areas from which the measurements would be taken were not damaged. Leaves from one tree were tied with a thread by the petioles and placed in a polyethene bag. If the collected material was not processed immediately, it was placed on the bottom shelf of the refrigerator, such material was kept for a maximum of one week. For long-term storage, a fixative was used: 70% alcohol or 3% formalin.

To exclude subjective errors when taking measurements from biological samples, the following was set: if the measurements were carried out by several people, then any individual sample was completely processed by the same person. After the measurement results were input into the electronic database and processed using the Statistica 12.0 software, the asymmetry value of every hanging birch leaf was ascertained. After statistical processing of the results of the features of each leaf, the average relative difference per feature was determined for this sample of leaves in the study area "plot 0-99" according to the example:

$$\text{Xav} = \frac{X1+X2+X3+\cdots+Xn}{100}, \quad (1)$$

where X_{av} – average relative difference per leaf feature; *X1, X2, X3…Xn* – asymmetry value of every hanging birch leaf.

The Pearson coefficients were used to calculate the correlations between the birch performance indices and the distance from the landfill. Linear regression models were used to evaluate the relative changes in the performance indices in space.

Dimensions were measured from birch leaf plates. Five factors were used to note indications from the left and right sides of a single leaf (Fig. 3): half of the leaves' width. Folding the leaf in half, securing the top to the base, and then unfolding the leaves allowed for measurements along the created fold; the distance between the bases of the first and second veins of the second order; the length of the second vein of the second order to the leaf's base; and the separation between these veins' ends; the separation between the leaf's top and the end of the second vein of the second order; the angle formed by the base of the second-order leaf vein's main vein and secondary vein.

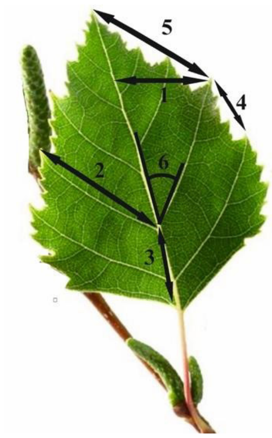

Figure 3. *Measurement of the angle between veins*
Source: *compiled by the authors*

The acquired result was equated with the degree of detection of deviations from the norm and their position within the general range of deviations in signs. The first four parameters were taken with a calliper, and the angle between the veins was measured with a protractor (Fig. 3). When measuring the angle, the protractor (1, Fig. 3) was held so that the centre of the base of the protractor window (2, Fig. 3) was at the branching point of the second vein of the second order (3, Fig. 3). Since the veins are not rectilinear but winding, the angle was measured as follows: the section of the central vein (3, Fig. 3), located within the window of the protractor (2, Fig. 3), was combined with the central beam of the protractor, which corresponds to 90°, and the section of the vein of the second order (3, Fig. 3) continued to the degree values of the protractor (3, Fig. 3) using a ruler.

The "bending" of the top of the leaf was recorded separately as "not bent", "bent to the left", "bent to the right", and "swallow's tail", which also potentially indicated that the leaves were subjected to technogenic influence. For the determination of parameters on the left and right sides, they were marked as Xl and Xr. For each of the 10 leaves of the same tree, the relative difference in the measurements of each of the 5 features on both sides of the leaf was determined using the formula:

$$FA_i = \frac{x_l - x_r}{x_l + x_r}, \quad (2)$$

where, FA_i – fluctuation asymmetry index; X_l, X_r – parameters on the left and right leaf sides.

Then, the average relative difference was calculated for each characteristic at each distance from the polygon. Fluctuation Asymmetry Integration Index (IIFA) values were then calculated for each leaf. To do this, the sum of the fluctuation asymmetry coefficients for each of the five sheet characteristics, divided by the number of measured characteristics, was calculated:

$$IIFA_n = \frac{FA_1+FA_2+FA_3+\cdots+FA_n}{n}, \quad (3)$$

where $IIFA_n$ – fluctuation asymmetry integration index; *FA* – fluctuation asymmetry index of each parameter.

This indicator characterizes the degree of asymmetry (Klingenberg 2015). If data sets demonstrated that fluctuating asymmetry exists, FA value was estimated using the protocol recommended by A. Palmer and Strobeck (2003). The last research step was to determine the level of air pollution in each area using a 5-point scale (Viscosi, 2015). To evaluate the level of disruption to the stability of plant development, a 5-point rating system was created. The first point (conditional norm), z_i fluctuates in the range from 0.040 to 0.054, the second point, from 0.055 to 0.059, the third point, from 0.060 to 0.064, the fourth point, and from 0.065 to 0.070 and above, the fifth point (critical state), are all within the range of values of the integral index of stability of development up to 0.070. The integral asymmetry index values that correspond to the first point are typically seen in a sample of plants that are growing in ideal conditions. If the plants are in extremely poor condition, the fifth point describes the critical state of the environment. The authors followed the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

One of the typical landfills in Ukraine is the solid waste landfill in Zhytomyr city. These landfills are typically run with little regard for environmental protection. In Zhytomyr City, all beforehand unsorted home waste is dumped in a landfill. This requires improvement as it has become a significant source of contamination for both groundwater and the atmosphere, thereby heightening the potential for an epidemic. Based on information presented during the 53rd session of the VII convocation of the Zhytomyr City Council (n.d.), from the moment the municipal landfill opened in 1957, between 12 and 15 million m3 of various waste was dumped, with a layer height of around 30 meters. The storage site occupies 18.7 hectares, but the overall area is 21.6 hectares (the state act on the allocation of land states that the total size is 21.5670 hectares). According to the 53rd session Decision at the landfill, waste of the 3rd and 4th class of danger from the city's population and enterprises of all forms of ownership is stored. The sources of waste include waste from high-rise buildings (about 63%); waste from private residential construction (about 26%); and waste from commercial and other business entities (about 11%). Household waste, dumped in the landfill, has the following declared morphological composition: 33.1% is food waste; 5.9% is paper; 3.3% is metal; 13.2% is polymer packaging; 4.1% is wood; 13.5% is glass; 2% is rags; 1.4% is leather and rubber; 3.7% is construction waste; 11% is road debris; and other waste is 8.8%.

Nevertheless, the lack of a weight scale at the municipal solid waste storage site raises questions about the accuracy of this data and the stated initial average coefficient of the solid household waste ratio of mass to volume (density), which is 0.27 t/m^3. The following environmental effects have been shown to have a significant negative impact: agricultural land alienation and landscape change; air pollution from the smouldering and burning of accumulated waste; potential harm from pathogenic microorganisms, dust, smells, and noise; noise pollution and pollution from the transportation of waste and the use of technical means; environmental thermal pollution; and pollution of surface and subsurface waters.

During research on the dendrology of the State Enterprise "Zhytomyrske LG" forests, the territory of which is closely adjacent to the territory of the Zhytomyr Municipal Solid Waste Landfill, the following species were discovered: *Birch pendula Roth., Populus alba L., Populus tremula L., Pinus sylvestris L., Salix caprea L., and Ashinus excelsior L.* The hanging birch was chosen as a research object since its effectiveness has been proven by Y. Petrushkevych and I. Korshykov (2020). As a result of the conducted research, the general indicator of asymmetry in the morphological parameters of the leaf plates of the *Betula pendula* species All data was divided into grades for better understanding and visualization of the data (Table 1).

Table 1. *Gradations of the main parameters of Betula pendula leaves in samples from phytocenoses subjected to different levels of anthropogenic pressure*

Leaf plate parameter	Parameter grades	Share in the sample of leaf plates of certain grades, %									
		location									
		0-99	100-199	200-299	300-399	400-499	500-599	600-699	700-799	800-899	900-1000
Leaf length, mm	⩽40.0	4.815									
	40.0-49.9	25.215	4.375	2.552	1.565	1.109					
	50.0-59.9	24.515	23.975	3.452	2.465	2.009	3.567	2.345	1.678	0.469	

Table 1. Continued

Leaf plate parameter	Parameter grades	Share in the sample of leaf plates of certain grades, %									
		location									
		0-99	100-199	200-299	300-399	400-499	500-599	600-699	700-799	800-899	900-1000
Leaf length, mm	60.0-69.9	21.315	25,530	17,252	13,335	12,879	9,651	14,568	13,098	10,034	12,456
	70.0-79.9	14.715	27,010	20,520	19,678	20,134	23,561	16,093	22,207	23,453	12,988
	80.0-89.9	9.430	10,580	27,130	26,143	26,599	32,992	30,021	33,524	31,008	31,455
	90.0-99.9		7,150	15,290	24,986	25,442	24,780	26,287	21,165	26,577	33,455
	100.0-109.9		1,380	10,250	9,263	8,812	4,447	8,456	7,098	5,457	4,679
	≥110.0			3,552	2,565	3,021	1,003	2,234	1,234	3,004	4,977
Width, mm	0.0-19.9	19.756	9,075	5,456	4,469	3,819	2,642	2,589	1,054	1,094	1,564
	20.0-39.9	26.031	32,974	9,123	8,136	7,486	6,789	8,965	7,567	6,541	7,789
	40.0-49.9	31.256	37,568	40,253	41,354	42,004	43,789	42,786	41,567	44,678	46,678
	≥50.0	22.956	20,463	45,257	46,046	46,696	46,780	45,660	49,812	47,687	43,969
Elongation of the leaf	≤1.50	1.874	1,256	1,025	0,038						
	1.50-2.00	22.456	9,623	5,462	4,475	3,825	4,678	4,910	3,001	2,870	1,987
	2.00-2.19	45.698	30,265	25,690	25,301	26,657	18,907	14,631	14,321	12,568	15,324
	2.20-2.49	22.150	30,565	35,456	33,720	34,687	38,789	31,678	27,081	23,609	26,788
	2.50-2.66	5.648	20,263	22,412	25,331	24,537	26,987	29,001	35,890	27,810	22,102
	2.70-2.99	2.547	5,968	7,536	9,768	8,301	10,123	18,906	16,710	21,614	29,450
	≥3.00	0.652	2,100	2,354	1,367	2,000	0,516	0,874	2,997	11,529	4,349
Distance from the central to the first vein, mm	≤2.0	3.772	2,870	2,460	1,486	1,578	0,567	0,110			
	2.0-2.49	3.154	8,770	9,434	8,497	6,678	4,789	6,898	2,678	3,897	2,475
	2.50-2.99	5.440	11,521	8,780	7,793	8,678	12,679	22,648	21,899	20,678	16,567
	3.00-3.49	22.444	22,161	20,456	19,469	13,567	28,543	35,679	39,543	33,268	32,789
	3.5-3.99	47.596	32,163	31,256	30,291	30,032	25,678	31,568	32,019	33,600	35,676
	4.00-4.49	15.050	18,910	23,456	25,598	26,789	21,897	20,500	20,165	18,562	24,808
	4.5-5.0	2.550	3,998	4,252	6,867	12,678	5,847	3,098	3,861	8,557	12,494
The distance between the first and second veins, mm	≤4.00	3.202	2,226	1,890	0,903	0,673					
	4.00-4.49	2.584	6,056	8,864	7,934	7,704	5,690	8,668	6,989	8,679	3,678
	4.50-4.99	4.870	7,425	8,210	7,223	6,993	7,743	8,437	5,678	8,547	9,072
	5.00-5.49	21.874	22,587	19,886	18,132	17,902	16,567	22,678	25,989	22,099	26,567
	5.50-6.00	45.156	35,146	30,126	31,234	31,464	30,466	33,678	32,678	29,678	36,679
	6.00-7.00	20.359	22,458	25,345	26,789	27,019	28,678	25,687	20,789	18,678	18,678
	≥7.00	1.980	4,459	5,896	7,789	8,245	10,857	0,852	7,877	12,320	5,326
The distance from the base of the leaf to the edge of the leaf, mm	≤2.99	22.485	6,725	4,004	3,017	0,750	0,189	0,037	0,000	0,000	0,000
	3.00-3.49	25.273	28,475	6,288	5,301	6,069	5,052	6,825	4,223	5,149	2,713
	3.50-3.99	26.285	31,549	30,986	29,999	14,109	13,110	15,239	13,966	13,931	13,654
	4.00-4.49	18.835	23,737	32,888	31,901	22,052	27,966	22,581	30,871	26,325	26,306
	4.5-4.99	4.715	5,290	13,565	15,678	28,678	27,710	30,108	29,709	30,363	31,485
	5.00-5.49	2.158	3,575	7,645	8,678	20,703	20,233	21,698	19,221	19,618	24,312
	≥5.50	0.256	0,690	5,125	5,429	7,639	5,740	3,513	2,010	4,615	1,529
Leaf apex numeric index	1.01-1.26	4.490	2,059			0,600	0,151	0,029			
	1.27-1.49	16.354	6,159	1,659	0,672	5,077	4,042	5,460	3,378	4,119	2,171
	1.50-1.74	29.565	33,259	28,156	24,017	11,689	11,201	12,660	11,508	11,238	10,923
	1.75-1.99	38.257	25,145	63,154	62,167	20,217	24,303	25,437	27,316	23,067	24,981
	2.00-2.24	10.145	17,290	5,859	12,872	26,969	26,880	28,090	30,501	28,981	27,786
	2.25-2.49	1.259	13,256	1,259	0,272	21,882	22,785	23,362	22,082	21,896	25,741
	2.50-2.74		2,859			13,565	10,638	4,962	5,215	10,699	8,398
Base numeric index	1.70-1.99	9.400	15,300				4,675				
	2.00-2.25	90.600	84,700	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
The apex shape asymmetry coefficient	0.25-0.49	61.524	57,980	74,300	75,587	75,070	72,770	74,425	71,598	73,357	72,347
	0.50-0.74	26.300	28,050	19,654	19,305	17,410	17,993	21,118	22,424	19,699	21,734
	0.75-0.78	11.400	9,300	6,100	5,113	7,521	7,128	3,754	4,188	6,944	3,110
	0.79-0.99	0.700	4,900				2,108	0,703	1,790		2,809
The base shape asymmetry coefficient	less than 0.015	60.062	50,154	55,154	55,683	53,910	46,333	54,601	53,006	54,201	49,097
	0.015-0.029	29.150	25,419	35,150	36,567	30,439	32,486	30,409	30,875	29,406	31,306
	0.030-0.044	7.156	14,250	7,162	6,175	7,401	8,402	8,928	11,920	8,510	9,103
	0.045-0.059	2.156	6,362	2,562	1,575	4,823	3,199	5,670	4,120	6,987	7,901
	≥0.060	1.595	3,862			3,427	9,580	0,392	0,079	0,896	2,593

Table 1. Continued

Leaf plate parameter	Parameter grades	Share in the sample of leaf plates of certain grades, %									
		location									
		0-99	100-199	200-299	300-399	400-499	500-599	600-699	700-799	800-899	900-1000
Integral index of FA	0.025-0.034	13,216	3,500			0,675	0,170	0,033	0,000	0,000	0,000
	0.035-0.044	25,245	9,800	3,300	2,313	4,573	3,294	4,573	2,851	4,067	3,879
	0.045-0.054	51,400	39,800	19,568	18,581	19,893	23,421	23,045	26,870	23,030	24,340
	0.055-0.064	10,156	39,156	53,150	54,634	50,303	45,302	46,532	45,002	47,201	46,533
	0.065-0.074		7,500	21,156	22,567	21,668	22,336	22,287	23,978	24,844	20,981
	≥0.075		0,900	2,895	1,908	2,887	5,476	3,530	1,299	0,858	4,267

Source: *compiled by the author's research results*

According to the results of research on the analysis and processing of data on the magnitude of asymmetry according to 6 parameters of birch leaf plates, the most stable parameter was determined – the length of the 2nd vein of the 2nd order from the base of the leaf (0.028), which proves its insensitivity to environmental factors. The most noticeable difference was between the sizes of leaf plates in length (Fig. 4).

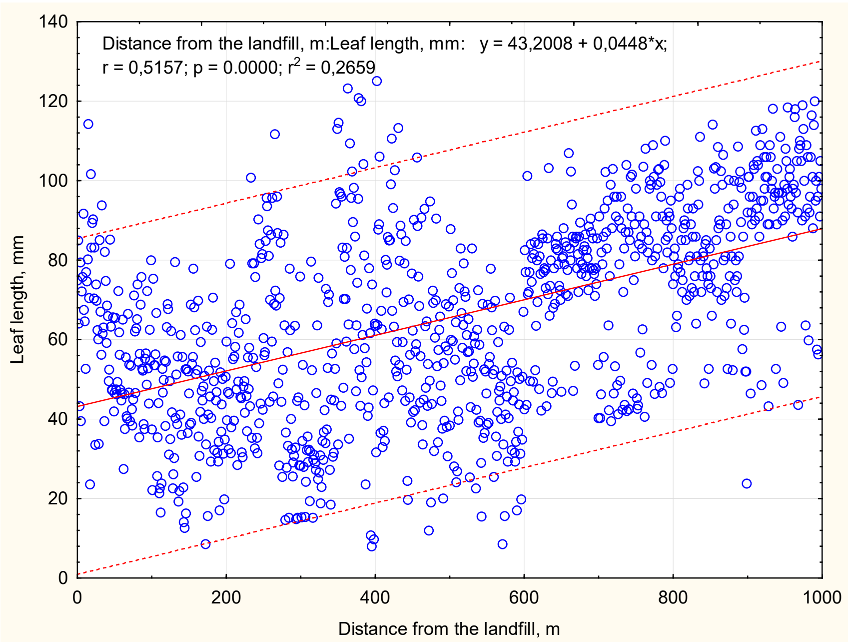

Figure 4. *Peculiarities of the formation of the dimensions of leaf plates in length depending on the distance from the landfill*

Source: *compiled by the authors*

It was noted that at a distance of up to 500 m from the landfill, the average size of leaf plates was smaller than at landfill at nearable distances. Thus, as follows from Figure 4, 80% of leaf plates in this range had dimensions from 30 to 80 mm, while at more than 500 m, these dimensions increased to 50-110 mm. This proves that the influence of toxic gases, leachate coming from landfills, and toxic substances in the soil has a significant negative impact on the surrounding dendrocenoses. Studies of the linear regression model showed that the coefficient correlation is 0.51, which indicates a medium-level relationship and characterizes the quality of the obtained regression line.

Based on the calculations in Figure 4, the regression equation is y=432008+0.0448x, where x is the length of leaf plates, mm, and y – is the distance from the landfill. The difference in the parameter of the width of the leaf plates was less pronounced. The processing of statistical data shows a less pronounced correlation dependence between the values of leaf width in closer and more distant areas from the border of the landfill. The collected data did not yield reliable correlation values (correlation coefficient: r=0.21). As per the research program, the distance from the central vein to the first vein was also measured. In general, the range of value variations was from 1.2 to 5 mm. In general, it was noted that the distance of the first vein from the central one depends on the degree of distance from the landfill in denrocenoses. Tangent to the limit, it is smaller and increases with distance. However, the correlation of these parameters can be characterized as directly proportional with a weak degree of closeness of the connection (r=0.25).

The difference between the distances between the bases of the 1st and 2nd veins of the 2nd order was significant and maximal in comparison with other investigated parameters. In general, the values of the indicators varied in the range of 3.38 to 7.60 mm. At the same time, the values of asymmetry according to this indicator were the highest, and the value reached 0.16. Based on all the measurements that were taken, asymmetry coefficients were found, and their integral index of fluctuation asymmetry was calculated by finding the average value of five different asymmetry measures for each leaf plate (Fig. 5). In general, the obtained values ranged from 0.012 to 0.077. At a distance of up to 500 m from the landfill, violations of the asymmetry of the studied leaf plates were noted. 80% of the values were in the range of 0.03 to 0.067. At a distance exceeding 500 m of the IIFI, 80% of the values were in a lower and narrower range, from 0.02 to 0.055.

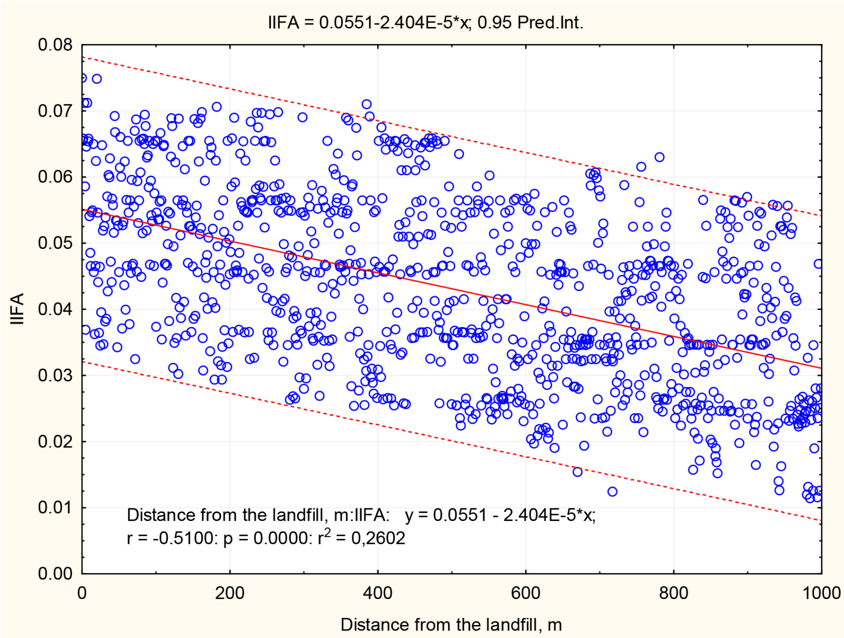

Figure 5: *Fluctuation Asymmetry Integration Index (IIFA) at various distances from the landfill's edge (in meters)*
Source: *compiled by the authors*

Linear regression model analyses revealed that the generated regression line's quality is characterized by a coefficient correlation of -0.51, indicating an inversely proportional link between the average level. The regression equation, where y is the distance from the landfill and x is the IIFA value, is y=0.0551+2.404E-5x based on the computations. The obtained IIFA values were equated to the threshold values for the stability of the development of dendrocenoses (Table 2).

Table 2. *The degree of atmospheric air pollution in the zone of influence of the Zhytomyr landfill (by the degree of leaf asymmetry)*

The score and value of the stability indicator. Degree of air pollution	Distance from the edge of the landfill, m	IIFA, X
1 point (up to 0.055) – clean air	beyond influence	0.046±0.0398
3 points (0.060-0.065) Air pollution	≥1000	0.067±0.0424
	900-999	0.067±0.0387
	800-899	0.068±0.0234
	700-799	0.060±0.0164
	600-699	0.062±0.0234
	500-599	0.062±0.0098
4 points (0.065-0.070) Heavily polluted air	400-499	0.067±0.0067
	300-399	0.068±0.0123
	200-299	0.068±0.0378
5 points (more than 0.070) Excessively polluted	100-199	0.072±0.0287
	≤99	0.083±0.0092

Source: *compiled by the authors*

The obtained data on IIFA levels were compared with air pollution scales, revealing that within a distance of up to 200 meters from the landfill border, the area was classified as "Excessively polluted", while up to a distance of 0.5 kilometres, it was categorized as "Heavily polluted". Starting from 500 m, the sheet plates also had certain deviations of asymmetry, which allows this territory to also be defined as "contaminated". Since the impact on the environment in the zone of the Zhytomyr solid waste landfill is limited only to the activities of the landfill itself (due to the absence of industrial enterprises, highways, and other factors), it is possible to conclude that the solid waste landfill has a significant impact on the development of the leaf plates of the hanging birch.

The leaves of woody plants are considered one of the most flexible and sensitive plant organs (Gawronski *et al.,* 2017) as they are in direct and long-term contact with the environment (Crini & Lichtfouse, 2018; Rodríguez-Santamaría *et al.,* 2022). The conducted research fully confirms these statements as the results presented in this study demonstrated the deformations in the formation of leaf plates in trees exposed to negative anthropogenic influence. Such plants change at morphological or physiological levels under the influence of long-term anthropogenic influence. R. Popek *et al.* (2018) determined that the greatest frequency of pollutants from the atmospheric air is fixed in the leaves, disrupts photosynthesis, and thus affects the physiological parameters of the leaves. This study analysed the precise manner in which this influence manifests itself on morphometric indicators. As such, comparable information was obtained, although concerning the landfill's toxic effects. In the same study, a negative relationship between FA and distance from the pollution source was found for several species of trees. This result seems quite reliable, although the authors used small sample sizes from two birch trees. The studied areas show great variability both in terms of the amount and composition of pollutants – this is a pulp and paper enterprise, a metallurgical plant, etc. In the presented study, the sample size, which allowed us to obtain completely reliable results, was significantly increased.

Similar conclusions that the morphometric indicators associated with the asymmetry of plants and their parts are informative indicators of the state of the environment were reached by other scientists. Studies by O. Bala & A. Terentiev (2017), as well as by O. Chornobrov and O. Tkachova (2021) confirm that the greater the deviation, the worse the conditions. This applies equally to both terrestrial and aquatic plants. Furthermore, more specific results were noted by M. Zbiljić *et al.* (2023). Their study indicated that the morphological diversification of leaves is another sign that shows how bad the conditions are. This is because it's considered one of the most crucial methods for assessing alterations in the plate's shape. Based on this study, this indicator has also been used for the presented research but did not get reliable results. Given this, this issue requires a more detailed study regarding the identification of environmental components that cause the deformation of the tips of leaf plates. Simultaneously, literature studies did not identify the distances between leaf veins as key indicator parameters.

CONCLUSIONS

By using degradation indicators to track the condition of dendrocenoses in the area under the influence of solid household waste landfills, this study addressed a real scientific and practical issue. While doing research, the following tree species were found in the forests right next to the Zhytomyr Municipal Solid Waste Landfill: *Pinus sylvestris L., Salix caprea L., Betula pendula Roth,* and *Populus alba L.* The technique of measuring the anthropogenic load near the solid waste dump using bioindicators – plates containing *Betula pendula* leaves, was effective. The accuracy of the procedure is demonstrated by the statistical estimations and the bioindicator results' resemblance to data collected by other authors.

The length of the second vein of the second order from the base of the leaf (0.028) was found to be the most stable of the five parameters of birch leaf plates. This shows that it is not affected by environmental factors. The difference between the distances between the bases of the 1st and 2nd veins of the 2nd order, where the asymmetry values exceeded 0.16, was defined as the maximum in the study. Further research should consider more indicator species since not all phytocoenoses contain the same list of species. Expanding the species diversity of indicator plants will help to be more flexible in monitoring ecosystems that are potentially subject to negative anthropogenic influence.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Біоіндикаційні особливості виду *Betula pendula Roth* у дендроценозах зони впливу полігону твердих побутових відходів

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Анотація. Проблема зростання чисельності та розмірів сміттєзвалищ в Україні зростає щомиті, оскільки окрім фізичного зайняття значних площ землі, сміттєзвалища впливають на навколишнє середовище та його компоненти через постійне надходження токсичних речовин у повітря, ґрунт і підземні води. Отже, метою роботи було дослідження екологічного стану дерев у дендроценозах, що розвиваються навколо полігону твердих побутових відходів (ТПВ). З огляду на це, у статті оцінено вплив полігону твердих побутових відходів м. Житомир на навколишні дендроценози на прикладі морфометричних змін показників листя виду *Betula pendula Roth*. Для цього досліджені розміри та особливості жилкування листкових пластинок на різній віддалі від полігону в межі до 1 км, а також визначені найбільш інформативні морфометричні показники. При цьому визначено, що найбільш стійким визначений параметр – довжина 2-ї жилки 2-го порядку від основи листка, а максимально чутливим – різниця між відстанями між основами 1-ї та 2-ї жилок 2-го порядку. На підставі отриманих даних щодо флуктуаційної асиметрії листкових пластинок узагальнено, що на усій досліджуваній віддалі є відхилення у морфометричних показниках, що дозволяють визначати середовище у діапазоні від «забруднене» до «надто сильно забруднене». Дані роботи можуть бути використані у якості експрес-методу оцінки масштабів впливу сміттєзвалищ на навколишні екосистеми при створенні санітарних захисних смуг, будівництві та обладнанні полігонів побутових відходів тощо

Ключові слова: береза; забруднення; відходи; жилкування; морфометричні показники