Екологічний Вісник Криворіжжя. 2023. Випуск 8. С. 13–23
Ecological Bulletin of Kryvyi Rih District. 2023. Issue 8. P. 13–23
ISSN 2664–505X (print) ISSN 2664–5068 (online)

THE IMPACT OF INDUSTRIAL CONDITIONS ON THE LEVEL OF FLUCTUATING ASYMMETRY OF THE LEAF BLADE OF *BETULA PENDULA* ON DEVASTATED LANDS

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Abstract. The article presents the results of assessing the variability of morphometric parameters of silver birch (*Betula pendula*) leaf blades on the devastated lands of the Petrovsky iron ore dump. The study utilized the results of our own research conducted from 2022 to 2023 on the territory of the Petrovsky dump in the Kryvyi Rih iron ore region. Investigations were carried out on technogenically disturbed areas that had not been reclaimed. It was found that the morphometric parameters of birch leaf blades exhibit clear ecological determinism. On all investigated plots characterized by a high level of pollution, the fluctuating asymmetry for *Betula pendula*, naturally occurring on the devastated lands of the Petrovsky dump, was determined to be 0.0556, indicating an approximation of the ecological condition to a pre-critical level. After calculating the average values of the integrated FA indicators across all sites, it was established that the most sensitive feature to adverse conditions in devastated lands is the distance between the bases of the first and second-order veins (0.132), while the most stable feature is the second characteristic (length of the second-order vein from the base of the leaf), which is 0.024. Maximum Spearman's correlation coefficients were recorded between the parameters: gross content of heavy metals in the soil of devastated lands and the level of fluctuating asymmetry in birch leaves ($r = 0.800$). The study demonstrates that woody plant species on the Petrovsky dump are generally subject to the influence of adverse environmental factors.

Keywords: Betula pendula, fluctuating asymmetry, correlation analysis, devastated lands, iron ore dump, Petrovsky dump, Kryvyi Rih.

Introduction. The exploration of the nature and repercussions of human-induced environmental effects, coupled with the adept management of these influences to safeguard the welfare of both human society and the broader ecosystem, represents a pressing contemporary concern. The environmental condition of Kryvyi Rih, as one of the most technogenically burdened regions in Ukraine, raises significant concerns. Each year, the anthropogenic pressure on nature intensifies, resulting in the emergence

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of disturbed land areas. Only in Kryvyi Rih, these areas cover an area exceeding 30 thousand hectares, acting as formidable sources of dust generation and causing a deficiency in nutrients for plants, consequently altering their hydrological regime [2, 3, 6]. It has been proven that all devastated lands (dumps, quarries, tailings storage facilities, industrial sites, etc.) significantly disrupt the environmental balance in industrial regions [4, 8, 9, 13, 17]. The problem of environmental pollution and the response of living organisms to anthropogenic factors remain relevant.

Evolutionarily, it has developed that leaves, as plant organs, are sensitive to changes in the surrounding environment. For the leaf blade of woody and shrub plants, a bilaterally symmetric structure is characteristic. They exhibit pronounced symmetry or minor deviations from it, provided they grow in favorable environmental conditions, serving as a marker of stable homeostasis [10, 12, 16]. Fluctuating asymmetry (FA) is a widely used tool to detect developmental instability and plants under stressful conditions are expected to exhibit increased values of asymmetry [5, 7, 12, 15, 19].

In previous studies, the content of nutrients and heavy metals in the leaves of dominant tree species on the iron ore dump in the Kryviy Rih basin was determined, along with the overall condition of the dendrocenosis [1, 18]. Exploring the impact of industrial conditions on the level of fluctuating asymmetry of the leaf blade of *Betula pendula* on devastated lands is crucial for comprehending the natural recovery of their populations. It also aids in assessing the influence of anthropogenic factors on the adaptation processes of plants existing in disturbed territories. However, the assessment of fluctuating asymmetry in the leaves of *Betula pendula* Roth. under the conditions of devastated lands in the city of Kryvyi Rih has not been conducted. Finally, we wrap up by delving into the study's contributions, emphasizing the practical implications of the paper, and exploring avenues for extending the research in future studies.

The object of this work: to investigate the asymmetry coefficient of *Betula pendula* leaves, which naturally occur on the devastated lands of the iron ore dump (Kryvyi Rih) and analyze the ecological conditionality of the indicators.

Materials and Methods. The study materials were derived from the results of our own research conducted throughout the years 2022–2023. The investigations took place on the territory of the devastated lands of the Petrovsky iron ore dump, situated in the Central part of the Kryvyi Rih region. Samples of *Betula pendula* leaves were collected within 5 temporary research plots (fig. 1) that differed in various ectopic conditions (age of the dump, composition of mountain rocks, micro and macro relief).

Figure 1. **Plan-scheme of Petrivskyi iron ore dump and the location of the test plots: I, II, III, IV, V — research sites**

The research adhered to the methodology introduced by Zakharov et al. [20], which requires 100 leaves (10 leaves from each of 10 trees) to characterize a single site. We rigorously followed this approach, deviating only in cases where there were fewer than 10 trees of the appropriate age at the designated site.

Measurements were taken for 5 parameters in millimeters (parameters 1–4) and degrees (parameter 5) on the left and right sides of the leaf blade (Fig. 2.13): half leaf width (left/right); length of the second-order vein from the base of the leaf (left/right); distance between the bases of the first and second-order veins (left/right); distance between the ends of these veins (left/right); angle between the main vein and the second-order vein from the base (left/right). Parameters 1–4 were measured using a measuring compass and ruler, while the angle between the veins (5) was determined using a protractor.

The magnitude of FA was assessed using an integral indicator – the value of the average relative difference for the traits, calculated as the arithmetic mean of the ratio of the difference to the sum of leaf measurements on the left and right. To achieve this, the absolute difference between the left (L) and right (R) measurements was divided by the sum of these measurements (Formula 1): $|L - R|/|L - R|$, (1)

Using the values of FA for each trait, the asymmetry index for each leaf was calculated. The obtained value was divided by the number of traits (Formula 2):

$Z = (Y1 + Y2 + Y3 + Y4 + Y5)/N$, (2)

where N is the number of parameters, and Y is the indicator calculated for each parameter as the difference between the right and left parts of the leaf blade.

After this, the average relative differences between sides were determined (Formula 3):

$Xcep. = (Z1 + Z2 + \ldots + Zn)/n$, (3)

n – is the number of leaves (100 pcs). The results were processed by standard methods of variation and correlation statistics at a 95% level of significance [14].

In table 1, an evaluation of the obtained results of fluctuating asymmetry is presented according to a five-point scale proposed by Zakharov et al [20].

Table 1. **Scale used for evaluating the environmental quality based on the developmental instability of *Betula pendula***

Score	FA Level	Assessment	
		Rank	Conditions
1	< 0.040	I	Conditional norm and minimal deviations
2	0.040 – 0.044	II	Minimal impact level
3	0.045 – 0.049	III	Average impact level
4	0.050 – 0.054	IV	Maximum impact level
5	> 0.054	V	Considerable deviations, critical state

The scale of deviation from the norm characterizes the level of territory pollution based on the FA indicator, where 1 point corresponds to the «conditional norm», and 5 points indicate a «critical state». Samples of *Betula pendula* leaves from trees in natural plantings in Gurivsky Forest (Kirovohrad region) were used as a control. The natural phytocenoses of this forest are located in the floodplain of the Bokova River, approximately 30 km away from industrial enterprises.

Results and its discussion. Having received and analyzed the results, we can conclude that the increase in levels of air pollution negatively affects the morphometric characteristics of birch leaves. This fact can be explained by the toxic impact of air and soil pollution with heavy metals on plants, leading to a reduction in leaf size. In our opinion, this phenomenon can be

explained by the effect of regional geochemical and biogeochemical anomaly, which is characterized by the increased content of Ferrum and Zinc. As previous research results have indicated, the growth and development of trees on devastated lands occur in the presence of a clear excess of heavy metals, especially Fe, Mn, and Zn [18].

In the devastated lands of Petrovsky waste rock dump, a decrease in numerical values for all indicators was observed compared to the values obtained in the control area of Gurivka forest (Kirovohrad region) (fig. 2).

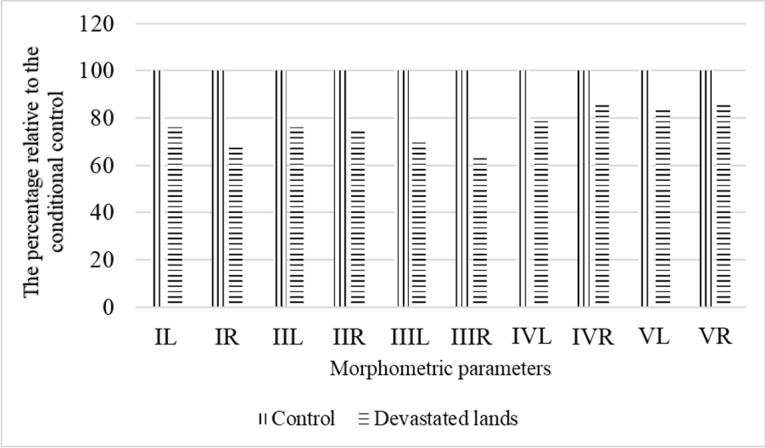

Figure 2. **Relative morphometric parameters of *Betula pendula* leaves under the conditions of the devastated lands of the Petrovsky dump (L — parameters of the left side, R — parameters of the right side)**

As previously stated, in the devastated lands of the Petrovsky waste rock dump, there was a decline in numerical values for all indicators compared to the values obtained in the control area of Gurivka Forest (Kirovohrad region).

After assessing the average values of the integral FA indicators in *Betula pendula* leaves, we can conclude that the most sensitive characteristic to adverse conditions of devastated lands is the distance between the bases of the first and second veins of the second order (0.132). The analysis of the obtained results revealed that the second characteristic among the five investigated parameters is the most stable, with a value of 0.024.

The study of leaf morphology indicators of woody plants, particularly

their fluctuating asymmetry, is a promising method for bioindication of environmental conditions. It is logical that increased levels of air pollution negatively impact the morphometric characteristics of birch leaves. The overall fluctuating asymmetry index of the leaf blade of *Betula pendula* shows significant differences across various research sites (table 2).

Table 2. **Assessment of *Betula pendula* developmental instability in the devastated lands of Petrovsky iron ore dump**

Five characteristics		Statistics				
		Min	Max	M±m	V%	P%
I	L	18	31	23.4±2.91	27.79	12.43
	R	19	31	23.8±2.75	25.80	11.53
II	L	30	40	34±2.26	14.85	6.64
	R	30	41	34.7±2.36	15.37	6.87
III	L	2	6	4,2±0,67	35.32	15.79
	R	2,5	6	4.9±0.64	29.22	13.07
IV	L	10	14	12±0.71	13.18	5.89
	R	10	13	11.3±0.62	12.36	5.53
V	L	40	58	49.2±3.22	14.61	6.54
	R	39	57	48±3.31	15.38	6.88

M — arithmetic mean, m — standard error of mean, CV% — coefficient of variability, P% — statistical significance, tst — Student's t-test.

Based on the calculation of the mean value of the fluctuating asymmetry, we established the dependence between the violation of symmetry levels and the environmental pollution. During the study, a general indicator of asymmetry of morphometric parameters of the leaf blade of *Betula pendula* trees was determined. Considering that the Petrovsky waste rock dump was formed for the storage of low-prospective iron ores, quartzites, shales, and loose rocks (clay, sand, and loam), the ecological conditions for the growth and development of woody plants appear to be challenging.

In the discussion, we compared the obtained data with the scale proposed by Zakharov et al. The maximum value of fluctuating asymmetry in *Betula pendula* was observed in plot 1 — 0.062. At locations 2 — 4, the fluctuating asymmetry coefficient varies within the range of 0.053–0.057. Minimal disturbances are observed in the samples collected at the fifth research site, amounting to 0.050. The research results indicate environmental pollution in the devastated lands. The challenging conditions for the growth of woody and shrub plants, where the pollution level approached five points, are

characterized as a critical state (>0.54) (table 3).

Table 3. **Fluctuating asymmetry index of *Betula pendula* and the environmental quality ranking**

Sample collection location	Comprehensive assessment of parameters		
	Fluctuating asymmetry index	Rank	Ecological assessment of the territory
Petrovsky iron ore dump–study plot I	0.062±0.002	V	Considerable deviations, critical state
Petrovsky iron ore dump–study plot II	0.053±0.001	IV	Maximum impact level
Petrovsky iron ore dump–study plot III	0.057±0.002	V	Considerable deviations, critical state
Petrovsky iron ore dump–study plot IV	0.056±0.001	V	Considerable deviations, critical state
Petrovsky iron ore dump–study plot V	0.050±0.001	IV	Maximum impact level
Control	0.032±0.001	I	Undisturbed, minimal deviations from the normal state

Table 3 presents the results of the integral asymmetry index of silver birch leaves in an area with minimal air pollution (located in Gurivka Forest), which is the lowest at 0.032. It has been determined that in the area of maximum air pollution, the indicators of fluctuating asymmetry (0.056–0.062) indicate extremely unfavorable conditions, with plants being in a severely suppressed state. The integral indicator of fluctuating asymmetry in plants from the first, third, and fourth plots of the Petrovsky waste rock dump corresponds to 5 points on the standard scale and reflects a «critical» state of the environment of the devastated lands for this species. The remaining research plots (second and fifth) are rated at 4 points, indicating unfavorable conditions of the devastated lands.

It should be noted that the I study plot, located on the first berm of the waste rock dump, where 60 years ago works on dumping of mountain rocks were carried out. The formation of the I and II study plots was completed 50–60 years ago. The self-revegetation period of the IV study plot does not exceed 45 years. It was found that the lowest FA indices were study

in the V plot, characterized by dense herbaceous cover, where significant associations of hydrophytes are present.

Ecological determinants of asymmetry coefficient in *Betula pendula* leaves on devastated lands in Kryvyi Rih. Our calculations confirm the possible connection between the content of heavy metals in the soils of the devastated lands of the Petrovsky iron ore dump and the indicators of fluctuating asymmetry in the leaves of the naturally occurring birch within the technogenically disturbed areas. In our ecological studies, we calculated Spearman's rank correlation coefficients. The most significant correlation relationships ($p<0.05$) were observed between indicators such as the metal content in the waste dump soils and the level of fluctuating asymmetry. Data on the gross content of heavy metals was taken from our previous studies on the Petrovsky iron ore dump. The Spearman correlation coefficient between the concentration of heavy metals and the level of fluctuating asymmetry is 0.800, indicating a strong positive monotonic dependence.

Conclusions. All available sources of information and the results of our own research have been summarized. Fluctuating asymmetry is a valuable tool for understanding the developmental repercussions of technological stress on plant organisms. The research results indicate that the magnitude of fluctuating asymmetry for silver birch (*Betula pendula*), naturally occurring on the devastated lands of the Petrovsky waste rock dump, is 0.0556.

This suggests an approximation of the environmental condition to the pre-critical level. It has been established that the most sensitive characteristic to adverse conditions in devastated lands is the distance between the bases of the first and second veins of the second order (0.132), while the most stable characteristic is the second feature (length of the second vein of the second order from the leaf base), which is 0.024.

The correlation patterns confirm our previous hypothesis that woody plants grow under complex ecological conditions of devastated lands. The maximum values of Spearman's correlation coefficients were observed between the parameters: gross content of heavy metals in the soil of devastated lands and the level of fluctuating asymmetry in birch leaves ($r = 0.800$).

Considering all the obtained results, it can be concluded that woody plant species on the devastated lands of the Petrovsky iron ore dump are in a stressed condition, which may lead to premature aging of plants and a decrease in phytooptimization functions. In our opinion, the selection of species naturally occurring in the devastated lands of Kryvorizhzhya will ensure the high efficiency of phytooptimization measures for anthropogenic

objects. Their restoration is complicated by low fertility potential and disrupted hydrological regimes.

The results of our research can be utilized in the development of technologies for the restoration of devastated lands in industrial regions.

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ВПЛИВ ПРОМИСЛОВИХ УМОВ НА РІВЕНЬ ФЛУКТУЮЧОЇ АСИМЕТРІЇ ЛИСТКОВОЇ ПЛАСТИНКИ *BETULA PENDULA* НА ДЕВАСТОВАНИХ ЗЕМЛЯХ

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Анотація. У статті представлено результати оцінки мінливості морфометричних параметрів листкової пластинки берези повислої (*Betula pendula*) на девастованих землях Петровського залізорудного відвалу. Матеріалами роботи слугували результати власних досліджень, які виконували упродовж 2022–2023 рр., на території Петровського відвалу Криворізького залізорудного регіону. Дослідження проводили на техногенно потрушених територіях, які не були рекультивовані. Встановлено, що морфометричні параметри листкової пластинки берези мають чітку екологічну детермінованість. Виявлено, що на всіх дослідних ділянках, які характеризуються високим рівнем забруднення, величина флуктуючої асиметрії для *Betula pendula*, що природно поширена на девастованих землях Петровського відвалу становить 0,0556, що свідчить про наближення екологічного стану до передкритичного рівня. Після підрахунку середніх значень інтегральних показників ФА за усіма майданчиками, встановили, що найбільш чутливою ознакою до несприятливих умов девастованих земель є відстань між основами першої та другої жилки другого порядку (0,132), а найбільш стабільною — друга ознака (довжина другої жилки другого порядку від основи листка), що складає — 0,024. Максимальні значення коефіцієнтів кореляції Спірмена було зафіксовано між параметрами: валовий вміст важких металів у ґрунті девастованих земель і рівень флуктуючої асиметрії берези ($r = 0{,}800$). Показано, що на Петровському відвалі деревні породи рослин, як правило, піддаються впливу несприятливих факторів зовнішнього середовища.

Ключові слова: Betula pendula, флуктуюча асиметрія, кореляційний аналіз, девастовані землі, залізорудний відвал, Петровський відвал, Кривий Ріг.