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MONITORING THE STATE OF ENVIRONMENTAL SAFETY USING PHYTOINDICATION METHODS TO ENSURE SUSTAINABLE DEVELOPMENT OF A TECHNOLOGICALLY LOADED CITY KREMENCHUK

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Abstract. Ecological aspects of sustainable development have recently attracted the attention of scientists. The article is devoted to the control of ecological safety based on the study of the state of plantations in the city of Kremenchuk using the method of fluctuating leaf asymmetry as an indicator. The research was conducted in recreational, residential, transport and industrial areas. It was found that the condition of green areasin the city of Kremenchuk is heterogeneous and depends on the level of anthropogenic pressure. Plants growing near traffic routes and in industrial areas are much weaker than those growing in recreational areas.. The main indicator of plant condition in the study was the fluctuating asymmetry of the leaf blade of pyramidal poplar and hanging birch. It was found that the integral values of this indicator differ in different parts of the city with different intensities of anthropogenic impact, with the maximum values observed in industrial and traffic zones where there is an intense impact of pollutants. The results of the study confirm the unfavourable ecological condition of certain areas of the technologically loaded city of Kremenchuk, and also indicate the importance of environmental monitoring of pollution and development of measures to improve the condition of green areas. The results of the study can be used to improve the methodology and theory of ecological safety and urban environmental protection in order to preserve and restore plant populations in cities.

Keywords: phytoindication, sustainable development, biogeochemistry, environmental monitoring, ecological safety methodology, environmental quality assessment

1. Introduction

In the context of sustainable development, green spaces are an integral part of the urban environment and fulfil a variety of functions. Not only do they create a pleasant atmosphere and embellish the urban landscape, but they also play an important role in sanitation, spatial planning and maintaining ecological balance. Plants help to reduce air temperature, regulate humidity and absorb toxic gases and noise. However, plants are also sensitive to environmental conditions because they are tied to the soil and cannot move. They are particularly affected in urban ecosystems. The great diversity of plants and their dependence on environmental conditions make them the subject of environmental monitoring.

Changes in plant physiology and biogeochemical processes lead to visible damage and structural changes (Rihas at al., 2016). Plants may exhibit chlorosis, necrosis, changes in leaf shape and parameters, slow growth, bud death, and problems with reproduction and shoot formation. Plant ontogeny changes significantly, ageing processes accelerate and life expectancy decreases (Alekseyeva, 2014).

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Urban plants are exposed to geochemical factors as well as significantly altered abiotic and biotic factors. The root system of plants is exposed to stressors such as changes in soil acidity, over-compaction, contamination of the root layer with toxins, salinity, lack of nutrients and lack of moisture. The above-ground part of plants is exposed to such factors as increased levels of gaseous pollutants in the air (sulphur (4) oxide, hydrocarbons, carbon monoxide, nitrogen oxides, etc.) and aerosol pollution, which negatively affect metabolic processes (Shmandiy, Bezdenyezhnykh, 2014). Plants, as objects of phytomonitoring, play an important role in studying the natural aspects of the urban environment. They can provide information on the short-term and long-term effects of pollutants on the environment. The threshold concentrations of pollutants that affect plants and animals are often very different. As existing standards are based on the responses of animal organisms, plants may be more sensitive indicators in some cases (Glińska-Lewczuk, Walna, 2011).

Based on the above, we state that the use of plant responses as bioindicators of urban environmental quality is an important area of environmental monitoring of the urban environment. Therefore, the aim of this work is to monitor the state of environmental safety of urban areas using phytoindication methods.

2. Methodology and methods of environmental quality assessment

Pyramidal poplar (Populuspyramidalis) and hanging birch (Betulapendula Roth.) were chosen as phytoindicators. Test plots were established at each monitoring site to measure tree diameter (in centimetres) with a measuring fork and height (in metres) with an electronic eclimeter. The density of the leaves (as a percentage of normal density), the presence of dead shoots on the trunk and the degree of damage to the leaf apparatus were assessed. Thedendrological survey provided data on the distribution of trees in the study areas according to condition categories: I – no signs of weakening, II – weakened, III – severely weakened, IV - drying out, V – fresh deadwood, VI – old deadwood).

The appearance of trees plays an important role in determining their vital status. We considered several main characteristics, each of which could be sufficient for our conclusion.

The vital status of woody plants was assessed according to the scale of V.A. Alekseev (Bessonova Ivanchenko, 2019). Based on the data obtained as a result of our tree inventory and assessment of their condition in the sample plots, we calculated an integral indicator of the relative vital status of the stands (denoted as Ln) using the formula:

$$\mathrm{L_n} = \frac{100_{\mathrm{n_1}} + 70_{\mathrm{n_2}} + 40_{\mathrm{n_3}} + 5_{\mathrm{n_4}}}{\mathrm{N}} , \qquad (1)$$

where L_n is the relative vital status of the stand, calculated by the number of trees, n_2–weakened, n_3– severely weakened, n_4 – of dying trees, forest or forest-forming species on the research plot (or 1 ha); N – total number of trees (including deadwood) in the sample area or 1 ha (Barabash, O. V., 2019).

The relative value of leaf asymmetry was determined as follows (Savos'ko, 2015; Tykhenko et al., 2022):

$$X_\mathrm{A} = \frac{|L-R|}{L+R}; \ {}_{\Pi}\mathrm{X} = \frac{Y_1 + T_2 + \cdots Y_n}{N} ;$$
$$\mathrm{X_I} = \frac{\sum Z}{n} = \frac{1}{n}\sum_{j=1}^{n} z_j , \qquad (2)$$

where X_A is the index calculated for each parameter as the difference between the right and left parts of the leaf blade, $_{\Pi}X$ is the relatively average difference between the parameters for each leaf; N – is the number of parameters; X_I is the integral index of asymmetry, n is the number of leaves.

2. Results and Discussion

In the period from 2021 to 2023, seventy plots in the town of Kremenchuk were surveyed. The results of determination of morphometric parameters are presented in Table 1. It was found that in 75 % of the points the degree of variation of these data is medium or low. There is a significant and high correlation between height and diameter (r > 0.70).

The residential zone is divided into three sub-zones: residential CP – the central part of the city (including public and commercial buildings, as well as "old" five-storey buildings); residential MB – neighbourhoods with modern multi-storey buildings; residential PS – the private sector (mainly one-storeyresidential buildings).

Table 1

Average values of morphometric parameters of trees by functional zones

Functional area*	Height (H), m		Trunk diameter at the level of 1.5 m (D), cm	
	Birch hanging	Pyramid poplar	Birch hanging	Pyramid poplar
Residential CP	19.0	23.0	27.6	35.2
Residential MB	7.0	17.2	15.0	39.1
Residential PS	11.0	21.0	32.4	37.0
Recreational	20.0	17.5	26.1	29.5
Transport	13.5	16.4	30.2	34.0
Industrial	13.3	19.2	22.0	33.5
Background	23.0	23.0	26.0	34.0
Background	19.0	21.0	23.0	29.0

During the study, more than 800 specimens of pyramidal poplar and about 400 specimens of hanging birch growing in the town of Kremenchuk were described in detail.

The results of calculations using formula 1 on the basis of data obtained in 2022–2023 are presented in Table 2.

A systematic survey of the condition of the plants revealed that the trees growing in the northern part of the city are currently in weaker condition than those on the right bank. In the south, most of the trees are unaffected by the disease and make up a significant proportion of the population. However, about 5 % of the pyramidal poplars in the study area are classified as “severely weakened”. The poplars in the residential and recreational areas are classified as “healthy” (80–100 % vitality). In the transport zone, weakened specimens predominate (50–79 % vitality index), and in the industrial zone, tree plantations are characterised as severely weakened (20–49 % vitality index).

The condition of the birch groves is particularly negative. With the exception of the recreational area, most of the stands of this species are classified as “damaged” and in the industrial area as “severely weakened”.

Table 2

Distribution of indicator species specimens by vital status, %

Species	Status category					
	I	II	III	IV	V.VI	L_n
1	2	3	4	5	6	7
Residential CP						
Birch hanging	6.7	86.7	6.7	0	0	67.7
Pyramid poplar	58.4	39.2	0	2.5	0	85.9
Residential MB						
Birch hanging	31.6	63.2	0	0	5.3	72.0
Pyramid poplar	86.2	13.8	0	0	0	95.9

Continuation of Table 2

1	2	3	4	5	6	7
Residential PS						
Birch hanging	58.8	17.6	5.9	0	0	73.5
Pyramid poplar	79.5	20.5	0	0	0	93.9
Recreational						
Birch hanging	75	15	5	5	0	87.8
Pyramid poplar	97.5	2.5	0	0	0	99.3
Transport						
Birch hanging	33.3	38.9	5.6	0	22.2	63.9
Pyramid poplar	35.0	55	0	5	5	73.8
Industrial						
Birch hanging	7.5	27.7	37.8	24.6	2.5	39.4
Pyramid poplar	11.8	29.4	41.2	5.9	11.8	49.1
Background						
Birch hanging	87.5	12.5	0	0	0	96.3
Pyramid poplar	89.6	10.4	0	0	0	96.9

Desiccation of indicator species is observed in the zone of influence of pollutant emissions from stationary and mobile sources. The causes of treedesiccation and decline in urban areas are usually attributed to several factors, including unfavourable soil conditions, lack of maintenance, soil and air pollution, mechanical damage and the effects of phytopathogens. In most cases these factors act in combination.

Roadside plantations are most stressed due to the intense impact of vehicle emissions and extreme soil conditions (especially due to over-compaction leading to impaired soil aeration), as are forests near industrial areas.

During the monitoring, organic material was also collected for further measurement of the fluctuating leaf asymmetry index (Karpenko, Bachyns′ka, 2022). The peculiarity of this method is that indicators of the state of organisms of different species are used to assess the “health” of the ecosystem, rather than ecosystem or population indicators in their pure form. In total, we surveyed about 1.200 trees in the town of Kremenchuk and analysed 6,300 leaves over the entire study period.

For each characteristic we calculated the relative values of asymmetry (formula 2). Table 3 shows the data for the years 2021–2023.

Table 3

Average values of morphometric parameters of leaf blades

Species	The coefficient of fluctuating asymmetry ($X_A \pm_{\Pi} X$)					
	the 1st sign	the 2nd sign	the 3rd sign	the 4th sign	the 5th sign	Integral indicator
1	2	3	4	5	6	7
Residential CP						
Birch hanging	0.037±0.007	0.023±0.003	0.107±0.017	0.049±0.008	0.025±0.004	0.048±0.008
Pyramid poplar	0.031±0.005	0.030±0.005	0.147±0.025	0.099±0.016	0.041±0.007	0.069±0.007
Residential MB						
Birch hanging	0.040±0.006	0.020±0.003	0.095±0.019	0.044±0.007	0.028±0.004	0.045±0.005
Pyramid poplar	0.033±0.005	0.028±0.003	0.130±0.024	0.105±0.018	0.035±0.006	0.067±0.007

Continuation of Table 3

1	2	3	4	5	6	7
Residential PS						
Birch hanging	0.030±0.006	0.022±0.004	0.076±0.010	0.049±0.006	0.033±0.004	0.042±0.006
Pyramid poplar	0.029±0.004	0.030±0.004	0.135±0.021	0.101±0.016	0.037±0.005	0.066±0.006
Recreational						
Birch hanging	0.038±0.007	0.020±0.004	0.072±0.013	0.048±0.007	0.037±0.006	0.043±0.008
Pyramid poplar	0.036±0.004	0.032±0.005	0.148±0.027	0.112±0.019	0.050±0.007	0.076±0.006
Transport						
Birch hanging	0.037±0.006	0.022±0.004	0.110±0.021	0.057±0.009	0.042±0.008	0.054±0.010
Pyramid poplar	0.037±0.006	0.040±0.005	0.169±0.022	0.121±0.015	0.058±0.009	0.086±0.007
Industrial						
Birch hanging	0.035±0.006	0.026±0.005	0.120±0.018	0.054±0.010	0.038±0.007	0.055±0.009
Pyramid poplar	0.032±0.004	0.033±0.005	0.187±0.032	0.122±0.018	0.064±0.009	0.087±0.007

It was found that the integral indicator of fluctuating asymmetry of pyramidal poplar leaves varies from 0.052 to 0.114, and that of hanging birch - from 0.003 to 0.115.

The assessment of the quality of the environment by the value of the integral indicator of developmental stability was carried out using Table 4.

Table 4

Scale for assessing the quality of the environment based on the value of the integral indicator of the stability of leaf blade development of the indicator species

Score	Indicator of developmental stability of hanging birch	Indicator of the stability of pyramidal poplar development	Degree of deviation from the norm
I	<0.040	<0.059	Conditional norm
II	0.041–0.044	0.060–0.069	Initial deviation from the norm
III	0.045–0.049	0.070–0.079	Average level of deviations from the norm
IV	0.050–0.054	0.080–0.089	Significant deviations from the norm
V	>0.054	>0.089	Critical condition

The values of the integral asymmetry index associated with the score I are usually observed in samples of plants growing under optimal environmental conditions. Critical values of the asymmetry index are observed under stress conditions, when the plant is in a state of severe oppression.

Based on the results of the study, it can be concluded that the ecological state of the environment in the town of Kremenchuk is heterogeneous. The minimum values of the coefficient of fluctuating asymmetry of pyramidal poplar leaves were recorded in the parks of the town. The values of this parameter increase up to 5 points in the industrial and traffic zones. This indicates a decrease in the sustainability of woody plants. Samples taken in the southern part of Kremenchuk, in the area of Yuvileinyi Park, had a minimum asymmetry coefficient. Their integral values correspond to two points, which is a slight deviation from the conventional norm.

The surveys for the industrial zone in the northern part of the city and near the main transport routes show a significant deviation from the norm. Particularly noteworthy are the sites near one of the city's main thoroughfares, Svobody Avenue, where there is heavy traffic.

In recent decades, 80–90 % of the pollutants emitted into the air in Kremenchuk have been associated with motor vehicles. Exhaust fumes can spread from the road to a distance of 100–200 metres and rise up to the eighth floor, mainly due to light fractions of SO_2 and NO_2.

As a result of the survey of most of the territory of Kremenchuk, different zones were identified according to the state of environmental safety: critical condition (11 % of points), significant deviations (39 %), medium deviations (25 %), small deviations (18 %) and conditionally normal condition (7 %). Based on the degree of deterioration of the urban environment, we distinguish the following functional zones: recreation, residential PS, residential MB, residential CP, transport and industry.

Fluctuating asymmetry is a random deviation from bilateral symmetry in the bilateral structures of the body. These changes in the development of the body reflect the impact of external environmental factors. Assessing the condition of urban areas using this indicator is a quick, simple and inexpensive method that is widely used to determine environmental stress. However, an increase in asymmetry can also be associated with mutations and hybridisation. Therefore, the main disadvantage of using fluctuation asymmetry as a diagnostic indicator is the difficulty in distinguishing between genetic changes and the effects of environmental factors.

Fluctuation asymmetry is the result of various environmental stressors. It is therefore impossible to determine the specific causes of disturbance to the stability of leaf blade development without additional biogeochemical studies. However, this morphological feature has been successfully used in a comprehensive bioindication assessment of the quality of the urban environment.

In the study area of Kremenchuk we found the presence of parasitic damage. Particularly widespread are rot lesions on poplars caused by pests such as leaf-eating insects, leaf miners and poplar moths. As trees age, their natural defence mechanisms weaken and their resistance to external stresses, including abiotic and anthropogenic pollution, decreases. Therefore, we believe it is appropriate to take a differentiated approach to the issue of revitalising plant populations. In Kremenchuk, measures are already being taken to prune dry tree tops, which encourages active growth of their ground parts.

The ecological condition of green spaces depends on their location and type. In urban areas, parks are the best places for trees to grow, while boulevards and squares are slightly worse and roadside planting is the worst. The situation is particularly problematic on the outskirts of parks and squares, where there is a high concentration of toxic gases due to the proximity of major traffic routes.

Soil conditions also affect forest health. Some areas are contaminated with heavy metals and oil products, which seriously affects the condition of green spaces and the stability of various tree species.

3. Conclusions

The condition of green spaces in different monitoring areas was found to be associated with different levels of anthropogenic impact. Signs of tree diseases such as dry tops, sparse leaves, chlorosis and necrosis occur as a result of prolonged contact of plants with atmospheric pollutants, as well as the penetration of toxins through the roots, impaired ventilation and soil structure, and lack of mineral nutrients for plants.

In the Kremenchuk study area, there is a close relationship between the condition of woody plants and the environment. Plants growing in recreational areas are considered healthy or slightly weakened, while those growing along motorways are considered significantly weakened. Meteorological conditions during the growing season affect the condition of tree plantations. Lack of moisture increases damage to the assimilation apparatus of plants under anthropogenic stress.

The integral index of fluctuating asymmetry ranged from 0.050 to 0.112 for pyramidal poplar leaves and from 0.002 to 0.114 for hanging birch leaves.

The highest values were observed in industrial and traffic areas. These areas are affected by the negative effects of pollutant emissions from stationary and mobile sources. Therefore, these areas are consideredunfavourable for the growth of woody plants.

The results obtained correlate with our previous studies by elemental analysis using the atomic absorption spectrographic method with photographic registration on the DFS-8 apparatus using the following plant species Hawthorn (CrataegusmonogynaJacq.), Rosehip (Rosa canina L.) and Tatar honeysuckle (Loniceratatarica) (Kolesnik et al., 2023).

We believe that monitoring the condition of green areas is a continuous system of operational control over violations of their stability, damage caused by pests, diseases and other natural and anthropogenic factors, as well as violations of their living conditions, pollution and the content of essential nutrients in the soil where they grow. It is a system that allows us to monitor the dynamics of these processes and to detect unfavourableplantation conditions at an early stage.

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