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Assessment of the degree of air pollution by fluctuating asymmetry of leaves of various tree species

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Abstract. Fluctuating asymmetry of the hanging birch (*Betula pendula* Roth), black poplar (*Populus nigra* L.), common ash (*Fraxinus excelsior* L.), common maple (*Acer platanoides* L.), common lilac (*Syringa vulgaris*) was evaluated as an integral measure based on five morphometric features of the plate. Samples of the leaf apparatus were taken at each point of technogenic load from the lower part of the crown of several close-growing trees of *Betula pendula* Roth, *Populus nigra, Fraxinus, Acer platanoides* and *Syringa* randomly select 30 intact leaves from each tree. In the future, calculations of the coefficient of fluctuating asymmetry were carried out in order to obtain an average value that determines the quality of the air environment corresponding to a certain score. An attempt was also made to find the correlation relationship of each bilateral feature with the average coefficient of fluctuating asymmetry. As a result, the correlation coefficient was equal to one, which corresponds to a high correlation. Considering this circumstance, it was decided to find a connection between the correlation dependence of the fluctuating asymmetry of the hanging birch with the fluctuating asymmetry of the leaf apparatus of poplar, maple, ash and lilac. The correlation coefficients were close to one, which made it possible to compile regression equations, with the help of which air quality assessment scales were compiled.

Keywords: birch, fluctuating asymmetry, leaf apparatus, correlation coefficient, coefficient of fluctuating asymmetry

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Оценка степени загрязнения воздушной среды по флуктуирующей асимметрии листьев различных древесных пород

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Аннотация. Флуктуирующая асимметрия березы повислой (*Betula pendula* Roth), тополя черного (*Populus nigra* L.), ясеня обыкновенного (*Fraxinus excelsior* L.), клена обыкновенного (*Acer platanoides* L.), сирени обыкновенной (*Syrínga vulgáris*) оценивалась как интегральная мера по пяти морфометрическим признакам пластинки. В каждой точке техногенной нагрузки из нижней части кроны нескольких близкорастущих деревьев березы повислой (*Betula pendula*), тополя черного (*Populus nigra*), ясеня (*Fraxinus*), клена обыкновенного (*Acer platanoides*) и сирени (*Syringa*) случайным образом отбирались образцы листового аппарата по 30 неповрежденным листьям с каждого дерева. В дальнейшем проводились расчеты коэффициента флуктуирующей асимметрии с целью получения средней величины, которая определяет качество воздушной среды, соответствующее определенному баллу. Также была сделана попытка найти корреляционную взаимосвязь каждого билатерного признака со средним коэффициентом флуктуирующей асимметрии. В итоге коэффициент корреляции был равен единице, что соответствует высокой корреляционной связи. Учитывая данное обстоятельство, было принято решение найти связь между корреляционной зависимостью флуктуирующей асимметрии березы повислой с флуктуирующей асимметрией листового аппарата тополя, клена, ясеня и сирени. Коэффициенты корреляции были близки к единице, что позволило составить уравнения регрессии, с помощью которых были составлены шкалы оценки качества воздушной среды.

Ключевые слова: береза, флуктуирующая асимметрия, листовой аппарат, коэффициент корреляции, коэффициент флуктуирующей асимметрии

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Introduction

The assessment of the stability of the development of living organisms is based on the analysis of their morphological structures, which represents minor directional differences in morphological characteristics from normative indicators arising as a result of violations of these signs in conditions of negative development. In the normal state of the OS, the level of their deviations is minimal, with increasing negative effects it increases, which leads to an increase in asymmetry. This method of assessing the quality of the OS is quite sensitive and allows you to record even minor deviations in the parameters of the environment, which do not yet lead to a significant decrease in the vital activity of the individual.

Plants have a wide popularity in the bioindication assessment of the air environment. The attached lifestyle forces them to adapt to adverse environmental changes by activating their physiological processes.

Since higher plants lead a stationary lifestyle, the processes of turbulent mixing of polluting components of the air environment, which together with CO_2 enter the plants, play a major role here.

The method of determining the quality of atmospheric air by the fluctuating asymmetry of the elevator apparatus of trees is not complicated. However, this method is based on painstaking work, in which a large number of leaves and measurements are analyzed. For example, for analyses of only 30 leaves, 300 measurements and 150 calculations are required, and if samples are taken from 5 trees, then the number of informative indicators determined increases to 1500. An increase in the complexity of work in a certain way reduces the efficiency of air diagnostics.

The hanging birch is not an indigenous species of WKO trees. It is available in the regional center and some other regional centers of the region. Therefore, it is impossible to determine the state of air quality where there is no birch for other trees, since scales for determining the degree of air purity by the fluctuating asymmetry of their leaves have not been developed for them. Such widespread bioindicator trees in the West Kazakhstan region include black poplar, common maple, common ash and common lilac, which belong to semi-shrubs.

The aim of the research. To assess the degree of air pollution by various types of trees with the determination of the scale of their individual bioindication characteristics, as well as to calculate a number of model equations that significantly reduce the time to assess the quality of the air environment in any locality without reducing the accuracy of the determination in comparison with the classical method.

Material and methods

In the course of the research, the impact of anthropogenic impact on the quality of the air environment was assessed in five places in the city of Uralsk, West Kazakhstan region of the Republic of Kazakhstan: Kirov City Park, railway and bus station, thermal power plant, central market.

The bioindication method for determining the degree of air pollution by the fluctuating asymmetry of the leaf apparatus of the hanging birch (*Betula Pendula* L.) was used as the basis for assessing the quality of the air environment in zones of various anthropogenic loads.

The principle of the method is based on the detection of violations of the symmetry of the development of the leaf plate of woody and herbaceous plant forms under the influence of anthropogenic factors.

The purpose of this analysis was an integral express assessment of the quality of the habitat of living organisms by the fluctuating asymmetry of the leaf plate of the hanging birch (*Betula Pendula* Roth). The magnitude of the fluctuating asymmetry of the leaf apparatus of the hanging birch was determined by five bilateral signs:

1. The width of the leaf blade to the left and right of the central vein.
2. The distance from the beginning to the end of the second vein.
3. The inter-vein distance inside the leaf between the first and second veins.
4. The inter-vein distance outside the leaf between the first and second veins.
5. The angle formed by the central vein and the direction of the second vein of the leaf [1].

The collection of the leaf apparatus of the hanging birch (*Betula Pendula*), black poplar (*Populus nigra*), ash (*Fraxinus*), common maple (*Acer platanoides*) and lilac (*Syringa*) was carried out after the complete completion of intensive leaf growth, i.e. from September 13 to 20, 2021. For the selection of the leaf apparatus, medium-aged plants were used, excluding young and old.

From each tree at arm's length and only from the shortened shoots, 30 whole, undamaged leaves are selected. Further analytical work with the measurements of the sheet apparatus was carried out in the laboratory of the university, where the left and right bilaterals of each sheet were carefully measured.

Measurements of bilaterial signs were carried out using a caliper, ruler and protractor. The data obtained were entered into a workbook.

Based on the results of the data obtained, the coefficient of fluctuating leaf asymmetry was determined for each indicator. The coefficient of fluctuating asymmetry of leaves was determined by the formula proposed by V.M. Zakharov as the ratio of the difference between the left and right values of a feature to its sum [2]:

$$\delta_d^2 \frac{\sum(d_{1-r}-M_d)^2}{n-1}, \quad (1)$$

$M_d = \frac{\sum d_{1-r}}{n}$ – average difference between the sides;

$d_{l-r} \frac{2d_l-d_r}{d_l+d_r}$ – difference of feature values between the left (l) and right (r) sides; n is the number of samples.

Qualitative signs are calculated by the percentage of the sum of asymmetric leaves:

$$M_A = \frac{n_a}{n_a+n_c}, \quad (2)$$

where, n_a is the number of asymmetric individuals; n_c is the number of symmetrical leaves.

In the future, the coefficient of fluctuating asymmetry was determined by the indicators and in general by the sheet plate, which was the total coefficient of fluctuating asymmetry.

The data of the average coefficient of asymmetry for all thirty leaves were compared with the tabular value by which the quality of atmospheric air was determined [3].

Research results and their discussion

As a basis for assessing the degree of disturbance of the stability of the development of the leaf apparatus, a five-point scale developed for the hanging birch was used, according to which the level of pollution of the studied territory was determined (Table 1) [4–5].

Table 1

Scale for assessing the quality of the air environment by the coefficient of fluctuating asymmetry of the hanging birch

Pollution score				
1 (clear)	2 (relatively clean)	3 (polluted)	4 (dirty)	5 (very dirty)
<0.055	0.056–0.060	0.061–0.065	0.066–0.070	>0.070

The reaction of the considered bilateral signs of the hanging birch in the places of the observed objects of research was ambiguous and was estimated within 1–4 points (Table 2).

The places of the bus station and the park area were the least polluted. The FA coefficient of the hanging birch leaf plate here was 0.027 and 0.044. For these places, the atmospheric air quality score was one, which corresponds to a good purity of the air environment.

For industrial sites and the central market, the environmental situation with air quality was at the level of the third and fourth points.

The effect of pollutants was observed on all bilateral signs of the leaf plate of the hanging birch.

As expected, the bioindication method for determining the degree of air pollution shows the presence of anthropogenic load on living organisms, not one of any pollutants, but their total exposure, determined by their chemical reactions with each other [6]. Thus, the assessment of the influence of external factors on the bioindicator (hanging birch) allows us to consider the coefficient of fluctuating asymmetry of its leaf plate as a set of processes occurring in the air and determined by five bilateral signs.

Table 2

The value of the fluctuating asymmetry of birch leaf blades in various places of determination

Place of definition	Definition parameters					Coefficient of fluctuating asymmetry	Atmospheric air quality score
	Width of leaf	Length of the second vein	Distance between the veins		Angle		
			Inside the leaf	Outside the leaf			
Park	0.013	0.020	0.057	0.028	0.021	0.027	1
Bus station	0.022	0.033	0.083	0.046	0.035	0.044	1
TPS	0.031	0.047	0.116	0.066	0.052	0.063	3
Central market	0.033	0.050	0.128	0.070	0.053	0.667	4
Railway station	0.030	0.045	0.116	0.064	0.048	0.061	3

Considering this circumstance, according to the indicator indicators of the hanging birch, an attempt was made to determine the correlation relationship of the average coefficient of fluctuating asymmetry with each of the five determined parameters of the leaf separately, the width of the leaf, the length of the vein, etc.

Correlation dependence determines the quantitative relationship of the quantity of interest with the factors affecting it. Thus, this dependence makes it possible to predict with certain accuracy the results of the relationship of the quality of the air environment with a certain bilateral sign of the hanging birch [7].

Determination of the arithmetic mean was

$$by\bar{x} = 0.129 \div 5 = 0.0258,\ by\bar{y} = 0.262 \div 5 = 0.0524$$

Then the squares of the relations are calculated:

$$\Sigma\,(x - \bar{x}) = \Sigma x^2 - (\Sigma x^2) \div n = 0.0036032 - (0.129)^2 \div 5 = 0.000275$$

$$\Sigma\,(y - \bar{y}) = \Sigma y^2 - (\Sigma y^2) \div n = 0.014844 - (0.262)^2 \div 5 =$$
$$= 0.0011152\ \Sigma\,(x - \bar{x})(y - \bar{y}) = \Sigma xy - (\Sigma x \times \Sigma y) \div n =$$
$$= 0.007313 - (0.129 \times 0.262) \div 5 = 0.0005534.$$

The correlation coefficient is determined by the formula:

$$r = \frac{\Sigma\,(\mathrm{x} - \bar{x})\,(y - \bar{y})}{\sqrt{\Sigma(x - \bar{x})^2 \times (y - \bar{y})^2}} = \frac{0.0005534}{\sqrt{0.000275 \times 0.0011152}} = 0.998.$$

It is believed that at $r < 0.3$ the correlation between the signs is weak. At $r = 0.3$–0.7 – average, and at $r > 0.7$ – strong.

In the future, to assess the reliability of the calculated correlation coefficient, its error, and the significance criterion and confidence intervals are calculated [8].

The standard error of the correlation coefficient is determined by the formula:

$$S_r = \sqrt{\frac{1 - r^2}{n - 2}} = \sqrt{\frac{1 - 0.998^2}{5 - 2}} = 0.032,$$

$$t_{05} = 3.18.$$

The confidence interval is determined using the Student/s criterion, which is found in the table, the number of degrees of freedom is assumed to be $n - 2$:

$$\boldsymbol{r} \pm t_{05} \times S_r = 0.998 \pm 3.18 \times 0.032 = 0.998 \pm 0.10.$$

Thus, it can be seen that the correlation coefficient of the first bilateral feature with the coefficient of fluctuating asymmetry turned out to be close to one, which indicates a very strong dependence, and the confidence interval indicates the size of the boundaries of the estimated parameter.

Table 3

Calculation of auxiliary quantities for calculating the correlation coefficient of the first bilateral feature of the leaf plate with the coefficient of fluctuating asymmetry

Pair number	Feature values		x^2	y^2	xy^2
	x (width of leaf)	*y* (coefficient of fluctuating asymmetry)			
Park	0.013	0.027	0.000169	0.000729	0.000351
Busstation	0.022	0.044	0.000484	0.001936	0.000968
TPS	0.031	0.063	0.000961	0.003969	0.001953
Central market	0.033	0.067	0.001089	0.004489	0.002211
Railway station	0.030	0.061	0.000900	0.003721	0.001830
Sum	$\Sigma x = 0.129$	$\Sigma y = 0.262$	$\Sigma x^2 = 0.003603$	$\Sigma y^2 = 0.014844$	$\Sigma xy^2 = 0.007313$

Similarly, the correlation coefficients of other bilateral signs with the coefficient of fluctuating asymmetry were calculated, which also showed their high correlation dependence (Table 4).

Table 4

Calculated regression equations for all bilateral features

Bilateral sigh	Correlation coefficient
Width of leaf	$r = 0.998 \pm 0.10$
Length of the vein of the second order from the base	$r = 0.997 \pm 0.2$
Distance between the bases of the first and second veins	$r = 0.983 \pm 0.318$
Distance between the ends of the first and second veins	$r = 0.992 \pm 0.22$
Angle between the main and second veins from the base of the leaf	$r = 0.978 \pm 0.48$

The high correlation relationship of the characteristic features of the hanging birch leaf plate with the coefficient of fluctuating asymmetry allowed us to further calculate the regression equation, which has the form:

$$y = \bar{y} + b_{yx} \times (x - \bar{x}).$$

Regression coefficient $b_{yx} = \frac{\Sigma(\mathrm{x} - \bar{x})\,(y - \bar{y})}{\Sigma(x - \bar{x})^2} = \frac{0.0005534}{0.000275} = 2.01.$

Thus, the regression equation by which the total coefficient of fluctuating asymmetry can be calculated using the indicator of the width of the hanging birch plate is:

$$y = 0.0524 + 2.01(x - 0.0258) = 0.0524 + 2.01x - 0.0518 =$$
$$= 2.01x + 0.0006.$$

By entering into the regression equation the average value of the parameter to be determined (the width of the sheet) determined in a completely different point of the city, it is possible to quickly and with great accuracy establish the coefficient of fluctuating asymmetry, by which to determine the air pollution score.

Similarly, regression equations were calculated for other bilateral features of the birch leaf plate with a coefficient of their fluctuating asymmetry (Table 5).

Table 5

Calculated regression equations for each of the determined parameters of the fluctuating asymmetry of the hanging birch

Defined parameter	Regression equations
Width of the halves of the leaf	$y = 2.01x + 0.0006$
Length of the vein of the second order from the base	$y = 1.343x + 0.0001$
Distance between the bases of the first and second veins	$y = 0.519x + 0.0007$
Distance between the ends of the first and second veins	$y = 0.949x + 0.0004$
Angle between the main and second veins from the base of the leaf	$y = 1.218x + 0.0015$

Hanging birch is a good indicator of the quality of the air environment. However, in addition to it, there are other types of trees that have a high indicator ability. These are black poplar, common ash, common maple and such a shrub as lilac. These types of plants can grow where the birch is hanging, for some reason it may be absent. Determination of the state of the air quality by other types of trees will greatly simplify the process of tasks assigned to assess the quality of the air environment (Figure 1).

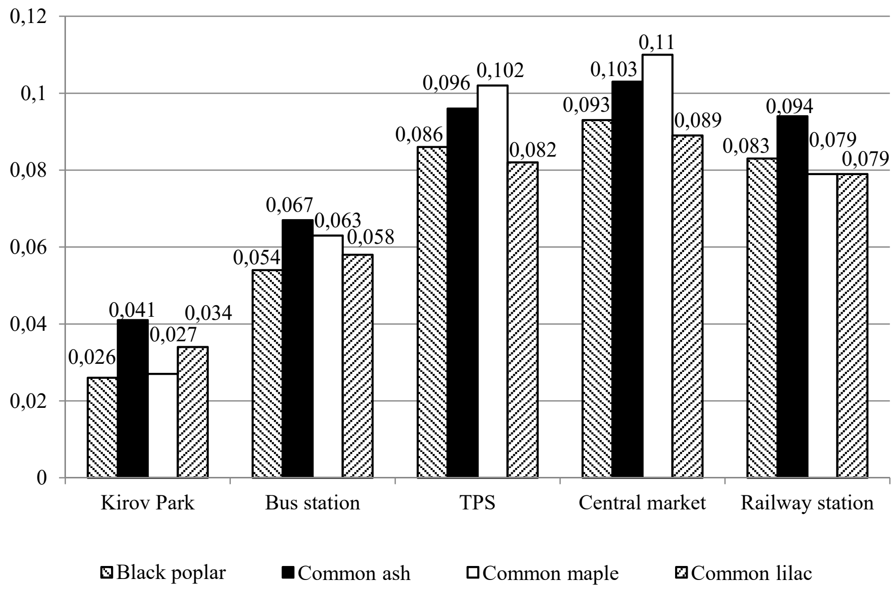

Figure 1. Coefficients of fluctuating asymmetry for other types of trees

All the above-mentioned indicators of fluctuating asymmetry of the studied tree species show that the influence of anthropogenic impact has almost the same reaction on them as in birch. However, these indicators were somewhat different than those of the hanging birch.

We also correlated the fluctuating asymmetry of the hanging birch with the fluctuating asymmetry of the leaf apparatus of poplar, maple, ash and lilac. Its value was with black poplar $r = 0.998 \pm 0.11$ with holly maple $r = 0.999 \pm 0.01$, with ash $r = 0.983 \pm 0.03$ with lilac $r = 0.998 \pm 0.12$.

In the future, taking as a basis a very high correctional relationship of the fluctuating asymmetry of the leaf apparatus of the hanging birch with the fluctuating asymmetry of the leaf apparatus of the black poplar, maple, ash and lilac, regression equations were calculated, with the help of which the boundaries of the air purity intervals were determined, which characterize the scale of pollution for each type of new bioindicators (Table 6).

Table 6

Air quality assessment scale based on the coefficient of fluctuating asymmetry of the sheet plate of the determined types of indicators

Bioindicator	Pollution score				
	1 (clear)	2 (relatively clean)	3 (polluted)	4 (dirty)	5 (very dirty)
Betula pendula Roth (x)	< 0.055	0.056–0.060	0.061–0.065	0.066–0.070	> 0.070
Populus nigra ($y = 1.7x - 0.07$)	< 0.074	0.075–0.082	0.083–0.091	0.091–0.099	> 0.099
Fraxinus excelsior ($y = 1.547x - 0.001$)	< 0.084	0.085–0.092	0.093–0.099	0.100–0.107	> 0.107
Acer platanoides ($y = 2.053x - 0.027$)	< 0.086	0.087–0.096	0.097–0.106	0.107–0.117	> 0.117
Syringa vulgaris ($y = 1.343x - 0.002$)	< 0.072	0.073–0.079	0.080–0.085	0.086–0.092	> 0.092

Certain interval boundaries allow you to set air pollution scores for black poplar, common ash, common maple and lilac. Thus, they allow, in the absence of a hanging birch, to determine the level of air pollution by other indicator plants.

Conclusion

During the study, a high correlation relationship was determined between the average coefficient of fluctuating asymmetry with all five bilateral signs separately, which ranged in sheet parameters from $r = 0.978 \pm 0.048$ to $r = 0.998 + 0.10$.

The high correlation relationship of the characteristic features of the leaf apparatus of the hanging birch with the coefficient of fluctuating asymmetry made it possible to calculate the regression equations for each leaf parameter separately.

The developed scales for determining the quality of atmospheric air by the coefficients of fluctuating asymmetry of black poplar, common ash and lilac make it possible to expand the range of species composition of indicator plants that quickly respond to the quality of the air environment under the influence of anthropogenic load.

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Bio notes:

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