Phytocenological study of environmental quality using the fluctuating asymmetry index Betula pendula Roth

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Abstract. The structure and species composition of communities of 9 areas within the city of Tobolsk (Tyumen region, Russia) and its surroundings were studied. The method used to assess the quality of the environment consisted in determination of the fluctuating asymmetry index of the Betula pendula Roth lamina. For spatial characterization of the state of the test object and assessment of the anthropogenic load, a bioindication map was drawn up using isolines. The environmental heterogeneity of environmental conditions and the degree of deviation from the environmental optimum were revealed. During the examination of groups of individuals, insignificant fluctuations in the nature of environmental conditions from conditionally normal (I point) to critical (V points) were noted. Such fluctuations are explained by the uneven distribution of pollution sources between the compared territories. It was established that under conditions optimal for a species, the smallest level of deviations from the norm is observed, and that the territory under study is heterogeneous in terms of the fluctuating asymmetry index.

1. Introduction

Changes in the environment under the influence of urbanization and human activities have become global. Such transformations intensify over time, which has led to the need to assess the negative changes in the state of the environment.

The most convenient markers for evaluation of anthropogenic impacts and environmental quality are bio-indicator plants. Throughout life, plants are attached to local territory and are exposed to soil and air. They represent a sensitive object that allows one to evaluate the complex of influences typical for a given territory as a whole, since they assimilate soil substances and lead an attached lifestyle. The condition of plants reflects, first of all, the pollution of a specific local habitat, which in most cases makes the assessment more convenient [1]. Of all plant organs, leaves are the most plastic one, and also the most sensitive to the impact of pollutants. This sensitivity is explained by the fact that most important physiological processes occur in the leaf. The simplicity and accessibility of leaf collection makes plants the most convenient object for research. Only leaves are generally needed for the analysis, which makes it possible to widely use intravital methods, in compliance with the current environmental requirements [2].

Currently, the method of phytodiversity of technogenic pollution is used. One of these methods is the determination of fluctuating asymmetry as an integral indicator of the state of the environment and at the same time an indicator of the sustainability of plant development. Fluctuating asymmetry (FA) is a number of insignificant macroscopic deviations from the strict bilateral symmetry of living organisms,
which independently manifest themselves to varying degrees on either side, and also do not lead to a
change in the species’ reaction norm. Such asymmetry is diagnosed by the normal distribution of
differences between the sides of the indicator. Fluctuating asymmetry characterizes the differences
between homologous structures within the same individual [3, 4].

Fluctuating asymmetry, defined as random deviations from the expected perfect bilateral symmetry
of an organism, has gained prominence as an indicator of developmental stability in ecotoxicology.
Fluctuating Asymmetry Index is the index of stability of the organism development. Studies of
fluctuating asymmetry primarily based on measurements of lengths and angles on the left and right sides
of organisms. Multiple sources provide information on environmental factors correlating with FA [5].

According to the above Guidelines, birch (Betula pendula (L.) Roth.) leaves are a traditional plant
object for study of the FA. The essence of the method is to determine the fluctuating asymmetry index,
which is a macroscopic deviation of bilateral traits of an organism in the process of development in
response to adverse environmental conditions. The phenomenon of fluctuating asymmetry is also known
under the synonym of stability of development. Thanks to comprehensive environmental studies, it is
possible to obtain an assessment of the ecological state of the environment as a whole [6, 7].

The purpose of this article is to assess the quality of the environment based on a bioindication
indicator - the index of fluctuating asymmetry in the Betula pendula Roth population.

2. Materials and methods

At the first stage of research, a reconnaissance survey of the territory of the city of Tobolsk (Tyumen
region, Western Siberia, Russia) was carried out.

2.1. Description of the studied areas

The vegetation was described during the growing seasons according to the methodological methods and
approaches adopted in phytocenology and widely used in geobotanical studies [8]. Used plots of size
20×20 m. The abundance of the species was determined according to the scale – a system of point-based
ocular estimate grades used for assessment of the abundance of the species: soc (socialis) – plants close
in on the above-ground part, completely; cop3 (from copiosa – copious) – very copious; cop2 – copious;
cop1 – fairly copious; sp (sparsae) – absentmindedly; sol (solitari es) – thin, scattered; un (unicum) –
occurs singly [9].

2.2. Fluctuating asymmetry

For bioindication assessment of the state of natural populations, the method of determining the
fluctuating asymmetry index [9] was used as an integral indicator of environmental quality and, at the
same time, an indicator of the sustainability of plant development.

The object of the study is Betula pendula Roth. The collection of material was carried out after the
leaf inflation stopped (July 1-4, 2019). Each sample included 100 leaves (10 leaves from 10 plants) from
each plot. The material was processed immediately after collection. Leaf blades were collected from the
bottom of the crown evenly towards the cardinal points. The selected leaf blades were normally
developed, medium-sized; those very different in size or damaged were excluded from the sample. The
examined plants did not visually show signs of defectiveness and clipped branches.

For measurement of fluctuating asymmetry, each leaf was placed with the side facing the top of the
shoot. For each leaf, indicators were recorded as per five measurements of the left and right sides of
the sheet. For measurement, the leaf was folded in half, combining the top with the base of the leaf blade.
Then the leaf was unfolded and measurements were made on the formed fold indicators: the width of
the left and right halves of the leaf; the length of the second order vein, second from the base of the leaf;
the distance between the bases of the first and second veins of the second order; the distance between
the ends of the same veins; the angle between the main vein and the second vein of the second order
from the base of the leaf.

To estimate the population (average) value of fluctuating asymmetry (FA) by a set of attributes, the
average relative difference between the sides per attribute was calculated - the normalized difference
[10,11], written in the following form (1):

\[
FA = \frac{1}{n \times m} \sum_{i=1}^{n} \sum_{j=1}^{m} \frac{|L_{ij} - R_{ij}|}{(L_{ij} + R_{ij})}
\]

(1)

where \(L_{ij}\) and \(R_{ij}\) are the values of the \(j\) attribute \((j = 1, n)\), respectively, on the left (L) and on the right (R) of the \(i\) leaf blade \((i = 1, m)\). In the first step, for each measured leaf, the difference between the measurements on the left (L) and on the right (R) is calculated, and then divided by the sum of the same measurements: \(|L - R| / (L + R)\).

In the second step, the asymmetry index for each leaf is calculated. To do this, the values of the relative asymmetry values for each feature are summarized and then divided by the number of attributes. In the third step, the integral indicator of developmental stability, fluctuating asymmetry, is calculated. To do this, the arithmetic mean of all asymmetry values is calculated.

Next, the case of assessing the stability of birch development was considered. A five-point grading scale was used to assess the degree of impaired developmental stability. The first point of the scale is a conditional norm. The fifth point is a critical value, such values of the asymmetry index are observed in extremely unfavorable conditions when the plants are in a very depressed state.

The results were evaluated on a 5-point scale of deviations of the state of the plant organism from normal conditions by the value of the integral indicator of the stability of development of Betula pubescens (I \(< 0.040; II- 0.040 - 0.044; III - 0.045 - 0.049; IV - 0.050 - 0.054; V - < 0.054) [12].

3. Results and discussion

To assess the population of the test object, we studied the distribution structure of individual groups of individuals throughout the city and suburbs. On this basis, 9 plots with presumably varying degrees of environmental pollution were identified, where studies were carried out at least once a year. Such an arrangement made it possible to minimize the amount of material collected, and at the same time to pay the greatest attention to areas with presumably high and medium anthropogenic impact.

The identification of the floristic composition, the list of species that form the phytocenosis, is the basis of the phytocenological study. The basis for the floristic analysis in the study was species lists of 9 geobotanical descriptions featuring Betula pendula Roth.

Plot 1. Birch forest of the goatweed-sedge type. Geographical coordinates: 58.491833º, E 68.68065º. On the site, the growth of trees of four species was noted: Betula pendula Roth, Pinus sylvestris L., Populus tremula L., Tilia cordata Mill (undergrowth). The grass cover is represented by: stratum 1 - Angelica sylvestris L.; stratum 2 - Centaurea scabiosa L., Bromopsis inermis (Leyss.) Holub, Geranium sylvaticum L., Lathyrus vernus (L.) Bernh.; stratum 3 - Trifolium medium L., Rubus saxatilis L., Vicia sylvaica L., Galium mollugo L. Dominated by: Aegopodium podagraria L. (cop1), Carex macoura Meinsh.(cop2).

Plot 2. Birch forest of the goatweed-sedge type. Geographical coordinates: N 58.070283º, E 69.043783º. On the site, Trees discovered: Betula pendula Roth, Pinus sylvestris L., Populus tremula L., Abies sibirica Lede. (undergrowth), Tilia cordata Mill. (undergrowth). Grass plants are distributed in strata as follows: stratum 1 - Angelica sylvestris L., Vicia sylvatia L.; stratum 2 - Galium mollugo L., Trifolium medium L., Geranium sylvaticum L., Lathyrus vernus (L.) Bernh., Aegopodium podagraria L.; stratum 3 - Rubus saxatilis L., Carex macoura Meinsh. Dominated by: Aegopodium podagraria L. (cop1), Carex macoura Meinsh. (cop2).

Plot 3. Birch forest of the goatweed-sedge type. Geographical coordinates: N 58.16375º, E 68.683º. The following types are marked: Betula pendula Roth, Populus tremula L., Pinus sylvestris L. (undergrowth). Grass plants are distributed in strata as follows: stratum 1 - Solidago virgaurea L., Filipendula ulmaria (L.) Maxim., Centaurea phrigia L.; stratum 2 - Aegopodium podagraria L., Ranunculus polyanthemos L.; stratum 3 - Trifolium medium L., Pimpinella saxifraga L., Lathyrus pratensis L., Vicia sepium L., Hypericum perforatum L.; stratum 4 - Carex macoura Meinsh. Dominated by: Hypericum perforatum L. (cop1), Carex macoura Meinsh. (cop2).
Plot 4. Birch forest of the sedge type. Geographical coordinates: N 58.5325°, E 68.692233°. Dominants were highlighted: *Betula pendula* Roth, *Abies sibirica* Ledeb., *Picea obovata* Ledeb. The grass cover is represented by: stratum 1 - *Milium effusum* L., *Solidago virgaurea* L.; stratum 2 - *Equisetum sylvaticum* L., *Rubus saxatilis* L., *Tridentis europaea* L.; stratum 3 - *Gymnocarpium dryopteris* (L.) Newman, *Vicia sepium* L., *Melampyrum sylvaticum* L., *Lathyrus vernus* (L.) Bernh., *Aegopodium podagraria* L.; stratum 4 - *Oxalis acetosella* L., *Maianthemum bifolium* (L.) F.W. Schmidt, *Luzula pilosa* (L.) Willd., *Rubus saxatilis* L., *Fragaria vesca* L., *Paris quadrifolia* L., *Carex macraura* Meinsh. Dominated by: *Carex macraura* Meinsh. (cop¹), *Aegopodium podagraria* L. (sp).

Plot 5. Birch forest of the short grass / oak fern type. Geographical coordinates: N 58.613017°, E 68.44535°. There are several types of trees on the site: *Betula pendula* Roth, *Populus tremula* L., *Picea obovata* Ledeb. (undergrowth). Grass plants are distributed in strata as follows: stratum 1 - *Aegopodium sibirica* L., *Aegopodium podagraria* L.; stratum 2 - *Rubus saxatilis* L., *Tridentis europaea* L., *Gymnocarpium dryopteris* (L.) Newman; stratum 3 - *Oxalis acetosella* L., *Maianthemum bifolium* (L.) F.W. Schmidt, *Carex macraura* Meinsh. Dominated by: *Gymnocarpium dryopteris* (L.) Newman (cop¹), *Carex macraura* Meinsh. (sp).

Plot 6. Birch forest of the sedge-shamrock type. Geographical coordinates: N 58.576417°, E 68.728783°. There are several types of trees on the site: *Betula pendula* Roth, *Populus tremula* L., *Picea obovata* Ledeb, *Tilia cordata* Mill. (undergrowth). The grass cover is represented by: stratum 1 - *Dryopteris carthusiana* (Vill.) H.P. Fuchs, *Delphinium elatum* L.; stratum 2 - *Equisetum sylvaticum* L., *Aegopodium podagraria* L., *Tridentis europaea* L., *Poa trivialis* L.; stratum 3 - *Gymnocarpium dryopteris* (L.) Newman, *Paris quadrifolia* L., *Stellaria holostea* L., *Stellaria bungeana* Fenzl.; stratum 4 - *Maianthemum bifolium* (L.) F.W. Schmidt, *Carex macraura* Meinsh., *Oxalis acetosella* L. Dominated by: *Carex macraura* Meinsh. (cop¹), *Oxalis acetosella* L. (cop²).

Plot 7. Birch forest of the dropwort-goutweed type. Geographical coordinates: N 58.081283°, E 69.0995°. On the site, the growth of trees of 2 species was noted: *Betula pendula* Roth, *Populus tremula* L. Grass plants are distributed in strata as follows: stratum 1 - *Aconitum septentrionale* Koelle, *Cacalia hastata* L., *Phragmites australis* (Cav.) Trin. ex Steud., *Pleurospermum uralense* Hoffm., *Angelica sylvestris* L.; stratum 2 - *Aegopodium podagraria* L., *Lathyrus vernus* (L.) Bernh., *Vicia sepium* L., *Trifolium medium* L., *Geranium sylvaticum* L., *Thalictrum simplex* L., *Filibendula ulmaria* (L.) Maxim.; stratum 3 - *Rubus saxatilis* L., *Pulmonaria mollis* Wulfén ex Hornem., *Elytrigia repens* (L.) Nevski, *Aegopodium podagraria* L. Dominated by: *Filibendula ulmaria* (L.) Maxim. (cop¹), *Aegopodium podagraria* L. (cop²).

Plot 8. Birch forest of the sedge-goutweed type. Geographical coordinates: N 58.166817°, E 68.44815°. Tree vegetation on the site: *Betula pendula* Roth, *Pinus sylvestris* L., *Populus tremula* L., *Tilia cordata* Mill. (undergrowth). Grass plants are distributed in strata as follows: stratum 1 - *Centaurea scabiosa* L., *Angelica sylvestris* L., *Calamagrostis arundinacea* (L.) Roth; stratum 2 - *Bromopsis inermis* (Leyss.) Holub, *Geranium sylvaticum* L., *Vicia sylvestica* L., *Aegopodium podagraria* L.; stratum 3 - *Galium mollugo* L., *Trifolium medium* L., *Lathyrus vernus* (L.) Bernh., *Hypericum perforatum* L.; stratum 4 - *Rubus saxatilis* L., *Carex macraura* Meinsh. Dominated by: *Carex macraura* Meinsh. (cop¹), *Aegopodium podagraria* L. (cop²).

Plot 9. Birch forest of the sedge-goutweed type. Geographical coordinates: N 58.412917°, E 68.44535°. Tree species: *Betula pendula* Roth, *Populus tremula* L. Grass plants are distributed in strata as follows: stratum 1 - *Cacalia hastata* L.; stratum 2 - *Solidago virgaurea* L., *Lactuca sibirica* (L.) Benth. ex Maxim., *Impatiens noli-tangere* L., *Aegopodium podagraria* L.; stratum 3 - *Equisetum sylvaticum* L., *Bromopsis inermis* (Leyss.), *Vicia sylvestica* L., *Brachypodium pinnatum* (L.) Beauv., *Deschampsia cespitosa* (L.) P. Beauv.; stratum 4 - *Vicia sepium* L., *Scutellaria galericulata* L., *Ranunculus repens* L., *Carex praecox* Schreb. Dominated by: *Carex praecox* Schreb. (cop¹), *Aegopodium podagraria* L. (cop²).

The study revealed heterogeneity of the emerging plant communities, which include species that differ in ecological and coenotic characteristics. The maximum number of species was recorded in plot 4 (22 species); the minimum number of species was recorded in plot 5 (13 species).
According to the results of the study, the developmental stability index in the *Betula pendula* Roth population growing in plot 4 is characterized by a slight deviation from the norm FA = 0.044 (I point).

Comfortable environmental conditions where individuals of *Betula pendula* Roth were found with the highest developmental stability were found in plots 6 (FA = 0.042, II points) and 7 (FA = 0.042, II points).

Less comfortable environmental conditions for the growth of the test object and the average level of deviations from the norm were found in plot 8 (FA = 0.048, III points) and in plot 9 (FA = 0.047, III points), between which there were no statistically significant differences.

Significant deviations from the norm were noted in plot 3 with FA = 0.051 (IV points), in plot 1 with FA = 0.052 (IV points), and in plot 2 with FA = 0.053 (IV points).

Plot 5 is characterized by maximum asymmetry indices – FA = 0.054 (V points). Comparison of fluctuating asymmetry indices demonstrated significant difference of this plot from all others.

In most cases, especially in environmental studies, the simple generation of data without taking into account their spatial distribution makes it extremely difficult to obtain an accurate analysis. By placing data on a map, one can grasp the nature of the distribution of objects or phenomena, trace their change in space and time, and draw certain conclusions (figure 1).

![Figure 1. Fluctuating asymmetry of *Betula pendula* Roth in the study area.](image)

Therefore, for the spatial characterization of the state of the *Betula pendula* Roth population, as well as the assessment of the state of the environment, bioindication maps of the study area were drawn up using the isoline contouring method. The use of the isoline method made it possible to identify the environmental heterogeneity of environmental conditions and the degree of deviation from the environmental optimum, not only in sampling locations, but also for other territories.

Thus, it was established that the territory under study is heterogeneous in terms of the fluctuating asymmetry index. Areas of ecological comfort were found, as well as areas with adverse environmental conditions.

Many researchers believe that some studies [12, 13] have shown that certain environmental conditions correspond to a certain level of errors in the development process. Moreover, this level may be completely different under other adverse conditions. These unfavorable conditions during development can affect only a specific species, in which case changes in development can be detected
only in it. At the same time, if the influence of a certain factor affects a group of species, a similar reaction will be seen in different species. The works released over the last decade have repeatedly confirmed that determining the level of fluctuating asymmetry gives a characteristic of the general condition of the biological entity [14, 15].

In these studies, adverse conditions during development can affect only a specific species, in which case changes in development can be detected only in it. At the same time, if the influence of a certain factor affects a group of species, a similar reaction will be seen in different species.

The publications of the last decade repeatedly demonstrated that determining the level of fluctuating asymmetry gives a characteristic of the general condition of the biological entity.

In this study, when examining groups of individuals, insignificant fluctuations in the nature of environmental conditions from conditionally normal (I point) to critical (V points) were noted. Such fluctuations are explained by the uneven distribution of pollution sources between the compared territories.

The analysis showed that 22% of the study area is occupied by areas with medium deviations from the norm (III points); the rest of the study area is distributed as follows: 22% - territories with minor deviations from the norm (II points), 33% - territories with significant deviations (IV point), approximately 11% - territories with conditionally normal state (I point), and approximately 11% - territories with critical environmental conditions (V point), which also coincides with the species richness of the studied territory.

It was found that the indicator of fluctuating asymmetry is one of the morphological methods for assessing the state and dynamics of biosystems, and the fluctuating asymmetry index is an indicator of the stability of the organism's development.

4. Conclusion
The indicator of developmental stability of the Betula pendula Roth population, expressed by the fluctuating asymmetry index, varies significantly. Plants in plot 5 experience a critical environmental effect, while the state of the environment in plot 4 is conditionally normal judging by the magnitude of the fluctuating asymmetry of the leaf apparatus of Betula pendula Roth.

Areas of ecological comfort were found, as well as areas with adverse environmental conditions. It was established that under optimal conditions for the species, the smallest level of deviations from the norm is observed; the territory under study is heterogeneous in terms of the fluctuating asymmetry index. The data obtained can be used for monitoring studies of plant communities in contaminated and anthropogenic areas.

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