Assessment of the Urban Air Environment Based on Bioindication Studies

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Abstract. The article is devoted to the study of the possibilities of bioindication for coniferous and deciduous woody and herbaceous plants for assessing the state of atmospheric air in an urban area where there is no significant anthropogenic impact and there are no large industrial enterprises. At the same time, there has been an increase in the population, an increase in the number and the development of small businesses and organizations, an increase in units of use and, consequently, an increase of vehicle traffic in the recent years. Studies were performed on both of these departments of the plant kingdom in order to compare the results. A dynamic analysis of the results of the study with archived data was also carried out.

1. Introduction
Nowadays, the assessments of the ecological environmental state, and especially the territories of permanent residence of the population are very relevant and widespread aspects of research in applied ecology. A variety of approaches are used, including expert solutions and author's approaches. For the most part, chemical-analytical methods are used, which is justified by the high accuracy of the analysis results and the comparability of the results [1]. However, sometimes these methods require the use of high-cost equipment, the availability of very narrow professional skills of employees, a long time to conduct research, and the cost of reagents and accompanying materials.

At the same time, rapid assessments are often required: both for general studies of the state of the territory, and, for instance, for determining the network of deeper observations. The responses of living organisms are classically used to register a rapid and complex response to pollution of a particular component of the environment. The priority here is to observe aquatic flora and fauna and study the relationship between the level of pollutants in water bodies and their accumulation by aquatic organisms [2]. Moreover, many studies have been carried out in the field of correlation analysis of the relationship between the levels of various chemicals in the soil cover and their accumulation by plants [3, 4, 5].

A much smaller number of works were conducted in the aspect of analyzing the response of plants to atmospheric air pollution, and this is the direction of the authors’ research. More often, plants are used to assess the impact on the atmospheric air of specific man-made systems of significant environmental impact or to study the territories of large localities [6, 7].

The territory of the presented research is a small city Dubna in Moscow region. The environmental situation in the city is quite prosperous, where there are no large enterprises, but in the last 10 years small enterprises and organizations have been actively developing, new facilities are open, a number of vehicles have been increased, an active work is underway, and an influx of population is seen.

The main objects of research are coniferous and deciduous plants: the state of needles of Scots pine Pinus sylvestris L. and indicators of fluctuating asymmetry of leaf plates of various woody and herbaceous plants Betula pendula Roth., Aegopodium podagraria L., Tussilago farfara L., Acer platanoides L. were analyzed.

Coniferous plants are convenient because they can serve as bioindicators all year round. The applied research method is based on the dependence of the degree of damage to Pinus sylvestris L. needles (necrosis and desiccation) on the level of atmospheric air pollution.
Fluctuating asymmetry of deciduous plants has many applications. In particular, it is an index of environmental and genetic stress. FA measures and shows developmental instability, which is related to individual fitness and is regarded as an indicator of an organism’s adaptation. Recently, several scientists have used fluctuating asymmetry to study integration, under the assumption that asymmetry separates parts and has a general tendency to develop foundations. Evolutionary biologists sometimes use fluctuating asymmetry as an indicator of individual fitness [8]. When studying the morphometric parameters of leaf plates, it is possible to speak and assert the presence of pollutants in the air basin of any territory or soil where plants grow. The presented study uses the postulate that under the optimal state of the environment, with a minimum number of disturbed natural conditions, the level of fluctuations is minimal, and with an increase in negative (most often anthropogenic impact), the level of violations increases, this process leads to the manifestation of asymmetry of leaf plates, as well as their indentation.

The bioindication method has gained popularity in the course of its development, due to the wide applicability of estimating fluctuating asymmetry among biological objects (in particular plants) and the simplicity of measurements compared to other types of analysis, as mentioned above. At this point, a large number of contradictory publications have appeared in the scientific literature that question the effectiveness of the method and the expediency of its use, since plants are affected by various factors, as well as due to the simplification of computational methods of analysis, substandard research results with systematic violations in the collection and storage of sampling examples [9]. It was found that the use of geometric morphometry for analyzing the biological shape and size of an object gives more advantages than linear and meristic features [10].

Despite all these problems, bioindication for coniferous and deciduous plants is common in many European countries [11, 12] and is often a solid basis for establishing a network of long-term regular monitoring, and serves as a supplement for evaluating the results of chemical and analytical studies.

2. Results and Discussion

During field work in Dubna the selection of biological material was made at 64 points for Pinus sylvestris L. and 123 points for deciduous plants, in all functional zones of the city (residential, industrial, recreational, urban forests). The assessment of the degree of air pollution by Pinus sylvestris L. was carried out on an assessment scale that includes the age characteristics of needles, as well as classes of damage to needles on shoots of the second year of life. To assess the quality of living organisms’ habitat by indicators of fluctuating asymmetry of higher plants, we used a point system developed at the Kaluga State Pedagogical University named after Tsiolkovsky K. by Streltsov A.

The data obtained (Fig. 1, 2) show an uneven distribution of atmospheric air pollution along the city perimeter, there are several areas with polluted air conditions, but most of the territory is characterized by a relatively clean air condition.

2.1. Study of foliage plants

Analysis of the spatial distribution of the integral index of leaf plate asymmetry of woody and herbaceous plants (Fig. 1) shows a fairly uniform distribution of the value of the indicator with a clear predominance of the territory with the characteristic of the habitat «relatively clean», normal.

The number of points with a clean environment higher plants is 11 points; number of points of territory with relatively clean, normal environment – 91 dot; 13 dots correspond to samples contaminated (alarm) characteristics of the environment; 8 sampling points score corresponding to the fourth gradation of zoning, which indicates a threat (dirty) state of habitat of plants. Areas with a very dirty (dangerous) state of the environment, characterized by the fifth point, were not identified on the territory of Dubna.
Figure 1. Schematic map of the distribution of the integral coefficient of fluctuating asymmetry in the deciduous plants on the territory of Dubna (scale of KSPU by Tsiolkovsky 2003)

0-0.0018 – pure; 0.0019-0.0089 – relatively clean («normal»); 0.0090-0.022 – contaminated («alarm»); 0.022-0.04 – dirty («danger»); > 0.04 – very messy («bad»)

The highest value of the coefficient (0.0397) is associated with a section near a fork in the road and a railway station. This section corresponds to an area with a dangerous (dirty) habitat of higher plants. This situation is due to high traffic, frequent braking on roads and near the site of the joint Institute for nuclear research (the city-forming enterprise). Contaminated sites identified on the territory of the memorial to the fallen soldiers in World war II, near the second city station, at the junction of the railway. Most of the territory along the only highway that carries traffic to and from the city is also in an alarming state here, the value of the integral indicator next to the traffic police post reaches 0.0307. This state of the environment is due to a high share of the influence of motor transport.

A section of territory in the center of the right bank of Dubna, the territory near the furniture factory «Ecomebel» and the plant «Tensor» with a large number of various industries is characterized by a polluted state of the environment. In an alarming (polluted) state in the left bank of Dubna there is a forest plot next to a cemetery and private residential development, the value of the integral indicator here reaches the level of 0.0099.

Most of the territory of Dubna corresponds to a relatively clean, normal characteristic of the habitat of higher plants that do not exceed the value of the integral index 0.0089. The minimum values of the integral coefficient were found in the left bank of Dubna near the beach (0.0009) and in the oldest area of the right bank Dubna near garden plots (0.0011), which also indicates a clean habitat for higher plants in these areas. The lowest values of the indicator were found in the Kozlakovsky forest, which was repeatedly considered as a promising area for creating a specially protected area of local significance. Almost the entire territory of the forest is characterized by a clean habitat.

2.2. Study of conifers

According to studies on Pinus sylvestris L., the prevailing level of air pollution in the territory of Dubna is the second (Fig. 2), that is the air is clean. These are the North-Western part of the left bank of Dubna,
the South-Western, southern, South-Eastern and Eastern parts of the right bank of Dubna. This is mainly the territory of the right bank of Dubna: the confluence of the Dubna and Volga rivers, the oldest inhabited areas. This includes residential areas, industrial enterprises, green areas and land plots. In the left bank of Dubna, this is a residential area.

Figure 2. Air pollution on the territory of Dubna according to Pinus sylvestris L. studies. 1 – the air is perfectly clean; 2-the air is clean; 3-the air is relatively clean («normal»).

The 4th level of air pollution is not mapped by interpolating the source data

Areas with level I air pollution (the air is perfectly clean) were identified mainly in the left bank of Dubna, and there are also some small areas in the right bank of Dubna. This is a small part of the territory in the North-West near the bank of the Ivanovsky reservoir, the Northern part and the North-Western and North-Eastern parts close to it, the Central part of the city, as well as local areas in the southern, South-Eastern and Eastern parts of the territory, where there is almost no anthropogenic activity. If you specify a more precise reference to the territory, then in the left bank of Dubna, half of the territory is characterized by level I air pollution and is located on the bank of the Volga river (700 m from the beach), between the garden Association and treatment facilities, this is the private sector and most of the special economic zone of the implementation type. In the right bank of Dubna I level of air pollution is characterized by almost the entire area of the right part in the direction of the arrow of both rivers Dubna and Volga. There are also 4 small plots with I level of air pollution: residential area of a newly built village on the bank of the Dubna river, a section near the railway to the South-East of the lake, a section near the old city cemetery and Kozlakovskiy forest near the village. The presence of sites with level I air pollution is probably due to the low impact of motor transport and economic facilities on the condition of Pinus sylvestris L. trees, since they are mainly located in green areas and residential areas.

There are 4 local areas with the third level of air pollution on the map: a small area in the Central part, two areas in the South-Eastern part, and one area in the North-Eastern part (close to the East). Territories with level III atmospheric air pollution (relatively clean air) are located near the landfill (currently under reclamation, but the object is subject to the past environmental damage), the area of the exit to the bridge over the Volga river, the territory next to the city boiler house and the area around
the transformer plant near the «Tensor». It is possible that these areas of deterioration of *Pinus sylvestris* L. trees are formed not only due to air pollution, but also due to contamination of ground water or its close occurrence to the surface, which naturally worsens the living conditions of trees. Several research points are located at bus stops.

On the territory of the city, there are 3 research points with an increased fourth level of air pollution, that is, the air is polluted. These points are located in the North-Eastern, Eastern, South-Eastern and Central parts of Dubna. These are points on the border of garden associations and forests near the landfill, territories near the city boiler house, and a transformer plant near the «Tensor».

2.3. **The comparison of the results**

A comparison of two approaches to assessing the ecological situation for coniferous and deciduous plants (Fig. 1, 2) shows good convergence of general characteristics, both zoning gradations indicate the predominance of optimal, relatively clean plant habitat conditions in the study area of Dubna.

According to the results of the study, we can say that deciduous plants are good bioindicators of the environment. Bioindication studies of this object provide a comprehensive characterization of atmospheric air, since the assessment includes squat and high-growing species, which can be used to determine pollution in a specific period of time.

*Pinus sylvestris* L. is considered as a bioindicator due to the high frequency of occurrence, uniform distribution in the city, availability for research and the possibility of year-round observations. It is a very sensitive indicator, and it reacts even to relatively low environmental pollution. *Pinus sylvestris* L. is appropriate to use as a bioindicator when the species is widespread throughout the entire region.

3. **Conclusions**

Based on the results of bioindication studies on coniferous and deciduous plants and comparison of the data obtained in 2019 with archival observations, a number of conclusions can be drawn.

In the absence of large industrial hubs in areas with a favorable environmental situation, however, areas of reduced environmental quality are identified. They are confined to sections of highways with high traffic intensity, local man-made systems that have been functioning for a long time.

For a more detailed study of the territory and verification of bioindication data, chemical and analytical studies of the identified problem areas, as well as the background territory, should be performed. The combination of methods will allow us to establish a network of monitoring observations that will record both the direct concentrations of pollutants and the response of the biological component of the ecosystem.

The use of coniferous plants is justified due to their cumulative effect, they can be used for long-term observations. Deciduous plants, on the contrary, are better used for analyzing the state of the environment in a short period, for a certain growing season.

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