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COMPLEX ASSESSMENT OF URBAN LANDSCAPES CONDITION BASED ON BIOINDICATION METHODS

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The analysis of anthropogenic pressure at urban territories has been conducted. The advantages of bioindication methods have been considered. Based on presented requirements to biomonitoring organization the most appropriate bioindicators for urban areas have been chosen. The methods of conduction and results interpretation approaches of plant bioindication have been described. The complex assessment scale for the definition of environmental disbalance degree at urban territory has been developed.

Keywords: bioindication, biomonitoring, environment condition, urban landscapes.

Проведено аналіз антропогенного навантаження на території урбанізованих ландшафтів. Розглянуті переваги методів біоіндикації. На основі представлених вимог до організації біомоніторингу були обрані оптимальні біоіндикатори для урболандшафтів. Описані методи проведення та підходи до інтерпретації результатів рослинної біоіндикації. Розроблена шкала для комплексної оцінки ступеня екологічного дисбалансу на урбанізованій території.

Ключові слова: біоіндикація, біомоніторинг, стан навколишнього середовища, міський ландшафт.

Introduction

Currently more than 50 % of the world's population is living in towns and cities. Migration from rural areas to urban zones is taking place in all developing countries as well as suburbs expansion in developed countries. Thus, the urban environment has become supremely important with regard to human health and wellbeing.

For centuries, urbanization has caused gradual transformation of natural environment components included in the area of its influence. It has been previously involved almost exclusively environment pollution with various wastes.

However, from the time of the Industrial Revolution onwards, both the scale of urban development and the degree of environment pollution rapidly increased introducing continuously widening spectrum of pollutants.

Problem formulation

The environment condition at urban territories is of the highest importance for all people living there, furthermore, it is the pressing issue for almost half of countries population. State authorities are responsible for chemical and physical components of environmental monitoring giving information about composition of urban air, waters and soils in relation to the presence of pollutants and their concentrations as compared to the existing standards. The obtained results give discrete or deducted reflection of environment condition. It is not able to produce integrated understanding or clear picture of the current situation, thus leaving the urban ecosystem health out of comprehension.

But urban ecosystems are able to reflect their condition itself and the main task is to detect and interpret these signs. All environment components are deeply fragmented at urban areas and they are very often isolated from each other so, that they cannot give reliable information about their natural neighbors. But there is all-in-one element of urban ecosystem which is directly connected with all others, actively reactive and clearly visible to human observers — biological objects and green plantations on the whole. They are small natural or artificial ecosystems – united organisms, which face all those negative factors of cities as humans do or even more. Increasing gaseous and dust pollution of air, special temperature and water conditions of air and soil, presence of stone, concrete and metallic surfaces, asphalt coverage of streets and areas, presence of underground communications and buildings in the area of root, additional illumination of plants in night-time, intensive mode of plantations usage cause specificity of urban environment and its dramatic difference from natural situation, where plants develop under the influence of biological and ecological factors. So, by detecting differences and changes of biota parameters it is possible to study the resulted state of the environment, assess potential risks and make further prognosis or develop some recommendations and take certain measures.

Publications analysis

For the efficient assessment of urban ecosystem it is essential to fully understand the diversity and properties of urban green plantations, to separate abnormalities from standard fluctuations. The grounds of biomonitoring as a inevitable part of environmental investigations have been laid by Y. A. Israel [1], R. Shubert [2], V.S. Nikolaevsky [3] and G.S. Rosenberg [4]. They have defined basic approaches and methods of biomonitoring, laid the principles of information acquisition and interpretation. The further development of this research field have been provided by Y. Bogach et al. [5] and B. Klausnitser [6], who have worked on principals of animal bioindication. M. Boyko [7] and A. E. Khodosovtsev [8] have presented the guidelines and results of boimonitoring using plants. Later the first complex investigations based on biomonitoring have been successfully carried out. At the same time the first attempts to develop integral scale for biomonitoring results interpretation was performed by I. Z. Kamanina et al. [9]. Now it is possible to combine various methods and approaches to develop multicomponent system of bioindication for urban areas environment control.

Purpose of work

The investigation was aimed at analysis of available bioindication methods in order to choose the most appropriate for urban conditions. Based on methods chosen, the multicomponent assessment scale is to be developed to provide the integral assessment of urban environment condition. These scale must include various indicators to provide as much information as possible about diverse biotic components state and, what is also of high importance, to verify the obtained results by each parameter against the rest.

Basics of biomonitoring and bioindication

The assessment of environment quality and anthropogenic changes within ecosystems of different levels can be carried out based on various biotic parameters (bioindicator monitoring). Advantages of biotic parameters usage include reliability and objectivity. The being of biota is determined by the condition of environment in its unity and expressly reacts to negative influences of any origin, regardless of our knowledge about them. Finally, the reaction of ecosystem substantially depends not only on composition of factors, but also on their interaction. But adequately reflecting the degree of negative influence on the whole, the bioindicators do not explain, which factor has created the response.

Biological indicators are species used to monitor the health of environment or ecosystem. They are any biological species or group of species whose function, population, or status can be used to determine ecosystem or environmental integrity. A good biomonitor will indicate the presence of the pollutant and give rough evaluation of the amount and intensity of the exposure. Bioindicators can tell about the cumulative effects of different pollutants in the ecosystem and about how long a problem may have been present, which physical and chemical testing cannot tell.

These organisms (or communities of organisms) deliver information on alterations in the environment or the quantity of environmental pollutants by changing in one of the following ways: physiologically, chemically or behaviourally. The information can be deduced through the study of the content of certain elements or compounds, their morphological or cellular structure, metabolic-biochemical processes, behaviour, or population structure(s).

Biomonitoring can be passive or active. Passive methods observe plants growing naturally within the area of interest. Active methods detect the presence of pollutants by placing test plants of known response and genotype into the study area. Depending on the organism selected and their use, there are several types of bioindicators: plant, animal, microbial and macroinvertebrate indicators.

The choice of bioindicators for urban conditions

Urban territories are not rich in fauna, therefore this type of bioindicators cannot be well applied in this case. However, I. Z. Kamanina et al. [9] offer to use the number of bird species as one of reliable parameters. An increase or decrease in birds population may indicate damage to the ecosystem caused by pollution. For example, if pollution causes the depletion of important food sources, some species dependent upon these food sources will also be reduced in number. Overpopulation, can be the result of opportunistic species growth. In addition, size and rate of deformities or diseases, which arise in bird populations, may be of great use. But more sophisticated methods, which involve study of other animal species, as well as macroinvertebrates or microbial indicators, lead to overcomplicated preparation and research techniques to be applied in order to receive clear results.

Therefore, the most appropriate group of indicators, which should be used at urban areas, is plants. The presence or absence of certain plant or other vegetative life in an ecosystem can provide important clues to the environment health assessment.

Plant bioindicators at urban territories and their investigation

There are several types of plant bioindicators, including mosses, lichens, tree bark, bark pockets, tree

rings, leaves, and fungi. By the increase of plants tolerance to the impacts of pollutants, they can be ranged as follows: lichens — coniferous — grassy — deciduous.

The choice of bioindicators depends on the following organism properties or qualities:

– living indicators must not be too sensible and too tolerant to contamination;

– living indicators must have a prolonged life cycle;

– living indicators must be wide-spread, thus every species must be linked to certain locality.

Lichens and mosses meet all this requirements. They respond to the pollution of atmosphere with the oxides of sulfur and nitrogen.

They react on contamination differently, if compared with higher plants.

Long-term influence of low concentrations of pollutants causes such damages to lichens and mosses, which do not disappear up to their death. This happens due to very slow process of dead cell substitution in lichens and mosses.

The fact is that lichens react on pollutants in two ways: gradually disappear under the influence of acid oxides and, at the same time, accumulate heavy metals in thallus, which also leads to their gradual disappearance.

This process can be divided into 4 stages:

1. Specific variety of lichens/mosses goes down.
2. Quantity of lichens/mosses goes down.
3. Size of lichen thallome and mosses bodies diminishes and losses color.
4. Concentration of heavy metals in the body grows constantly.

The methods of licheno- and bryophytaindication can be divided into three groups:

1. The methods based on identification of changes, which take place in the structure and vital functions of lichens under the influence of lichens.
2. The methods based on description of lichen species dwelling in districts with different level of atmosphere pollution.
3. The third group includes the methods of study of whole lichens associations in polluted areas and making special maps.

In relation to air pollution, the types of lichens and mosses can be divided into three categories:

1) most sensible, vanishing at the first signs of pollution;

2) medium sensitive, which substitute the most sensible vanished species, which they could not compete with, while the air was clean;

3) resistible, tolerant to pollution.

Based on individual features of lichens special scales of pollution, which allow defining the level of pollution based on presence or absence of certain species of lichens, are developed. In general, fruticose lichens are the most sensible to air pollution, crustose lichen are the most resistible, and foliose lichens are moderately sensitive.

Arboreal plants due to their spread, long life term, accessibility and variety are still the most efficient bioindicators.

The condition of trees is determined visually by the sum of basic biomorphological signs: crown density, foliation or level of defoliation, size and color of leaves (needles), presence or absence of deviations and deformations in the structure of trunk, crown and sprout, presence and share of dry sprouts in the crown or dry top, integrity and state of bark and oak. All these signs are produced by negative natural and anthropogenic environmental factors.

The integration of all those mentioned above parameters can be used for integral trees condition and environment quality assessment.

Evaluation of trees condition is conducted by two methods, supplementing each other. First, trees are divided into three quality groups in city planting regulations: 1 — good, 2 — satisfactory and 3 — unsatisfactory conditions. Secondly, on the basis of the operating «Sanitary rules in the forests of Ukraine» [10] there are 6 categories of trees viability: 1 – trees without the signs of weakening, 2 — weak, 3 — extremely weak, 4 m drying, 5 m dead trees of current year (dried in the current year), 6 — dead trees of past years. This type of assessment can be conducted for big territories and accompanied with sampling for further investigations.

As it was said, coniferous trees are more sensitive to environment pollution. The characteristic signs of environment deterioration and especially air pollution are the appearance of different sorts of chlorosis and necrosises, diminishing of organs sizes (length of pine-needle, sprouts of current and past years, their thickness, size of cones, reduction of size and number of final buds). The last is pre-condition of branching diminishing. Due to slowed growth of sprouts and needles at polluted areas the distance between needles is reduced (there are more needles per 10 cm of a sprout at polluted areas comparing to those of clean areas). Duration of needles life also diminishes (1–3 year at polluted area and 6–7 years at clean). Influence of pollutants also causes sterility of seed (reduction of their germination). All these signs are not specific; however, their sum gives the objective picture.

The biggest advantage of coniferous is that they could be used as bioindicators during the whole year. They are also very often found in the composition of protecting green belts and therefore may be used to assess environmental impacts of industrial enterprises or highways.

Deciduous trees have their own advantage: they change their leaves every year, so deviations from normal environment state detected with their help will be related to very specific period of time.

Leaves are also good object for further investigation in lab, namely the investigation of their condition based on the phenomena of asymmetry.

In this case, any species, for which bilateral symmetry is typical, can be chosen as a test-object.

Differences in width of left and right halves of leaf, length of vein of the second order, distance between the bases of the first and second veins of the second order, distance between the ends of the same veins and angle between the main vein and the second order vein of the leaf.

These values could be converted into numbers and thus quantitive assessment of bioindicators will be performed and the results will look more reliable and could be easily compared.

Further it is possible to evaluate the level of technogenic pressure at the area of investigations by studying signs of leaves damage.

The thing is that tissues of arboreal plants leaves, damaged as a result of anthropogenic pollution of air, do not take part in photosynthesis and stop to execute the basic functions: synthesis of organic substances, oxygen and phytoncydes production. The dust retaining role of urban plant is also weakened, as dust settles down on slightly moist surface of living leaves. The photosynthesis function highly depends on the area of leaf surface (leaf index).

So, the area of leaves is an important bioindicating parameter, which can be easily compared with that of background trees.

The visual methods of leaves area estimation and percent of damages of leaf tissues are not very exact, although on the whole they reflect the general picture of damages and green plantations condition.

Application of simple reagents (acids) gives possibility to distinguish really dead tissues from others and thus increases accuracy of the results.

Also it is possible to apply lab techniques for the investigation of tree leaves resistance to high and low temperatures, dusting and salinization, which gradually deteriorate under the influence of anthropogenic pressure at urban territories.

Finally, number of species and condition of grasses is also important for the assessment of environment quality of cities.

The most important parameter would be diversity of grasses, their average height and average length of leaves.

These should be also compared with the corresponding parameters of grasses, grown in natural conditions.

Bioindication results interpretation

All the results obtained in the course of biomonitoring at certain territory will be subjected to certain criticism due to mostly qualitative character and absence of strong theoretical grounds for their interpretation.

However, if the investigation is based on a range of methods applied and indicators studied, then the result will have higher credibility.

The fragment of the complex biomonitoring scheme for urban territory and interpretation of the obtained results is presented below (see Table).

Evaluation scales of natural environment components

Natural component	Index	Level of environmental disbalance (anthropogenic pressure)				
		minor	low	medium	high	catastrophic
Vegetation	Index of leaves fluctuating asymmetry	< 0.040	0.040–0.044	0.045–0.049	0.050–0.054	> 0.055
	Condition of leaves/needles of arboreal plants and grasses (qualitative)	green, normal sizes; crown is thick, normal form; damage and illnesses signs or absent	lighter than ordinary; crown is poorly foliated; growth is weak l, crown contains less than 25 % dry sprouts; signs of local damage	smaller or lighter than ordinary, grayish, mat; crown is sparse, dry sprouts from 25 to 50 %, the growth of sprouts is diminished more than half as compared to normal; signs of sprouts damage, illnesses and damages	more shallow, lighter or more yellow than ordinary, often prematurely falls off or dry; crown is very sparse, more than 50 % dry, the growth of sprouts is strongly diminished, signs of pests settling	drying, dried or fallen off prematurely, needles are grey, yellow or brown; crown is dried, but small sprouts and bark are saved; signs of pest settling on trunk, sprouts and roots

End table

Natural component	Index	Level of environmental disbalance (anthropogenic pressure)				
		minor	low	medium	high	catastrophic
	Condition of leaves and grasses (quantitive): Fluctuations of leaves area and needles length, distance between leaves, branching	< 5%	6–15%	16–25%	26–40%	> 40%
	Number of grass species per ha	> 30	21–30	11–20	6–10	< 5
	Number of lichen species per ha	> 8	6–8	3–5	1–2	–
	Number of mosses species per ha	> 7	5–7	3–4	1–2	–
	Percentage of lichens cover of trees	> 45 %	44–35	34–25	24–10	<10
Animals	Number of birds species	> 20	11–20	3–10	1–2	0

The results obtained in the course of the offered sequence of urban biomonitoring must be evaluated based on comparative scale, which could be supplemented with point scores.

The scale ranges the values of studied parameters to reflect the level of environmental disbalance in the following order – minor, low, medium, high, catastrophic.

The corresponding score is made of points obtained for each parameter, if minor level is equal to 0 or 1, low — 2, medium — 3, high — 5, catastrophic — 7. Depending on the number of parameters evaluated, the environmental situation at the study area will be interpreted.

The proposed biomonitoring scheme includes 20 parameters, consequently, the most favorable environmental conditions will be at urban areas with the score below 20, 21–40 stand for normal conditions, 41–60 corresponds acceptable situation, 61–80 marks the disturbed condition, 80–100 means that the environment condition imposed high risks for population and if the score is over 100, then the ecosystem is ruined and dangerous for population.

Thus, based on combination of various parameters of living bioindicators it is possible to define the level of environmental disbalance and develop a range of recommendations for further degradation prevention.

Conclusions

Intensive development of urban infrastructure and residential construction leads to the growth of competition for available land resources as well as access to the residuals of natural ecosystems within the city. This way green islands of cities become both needed element for normal life and physical obstacle for urban expansion. But the essence of green plantations role for urban settlements and residence is far beyond provision of visual attraction and free space.

These green objects form appearance of the city, have sanitary-hygienic, recreational, landscape-architectural, cultural and scientific value. The latter means, that they can provide valuable information about the environment quality and level of anthropogenic pressure at urban area. The proposed combination of bioindication methods is an efficient instrument simple to use and reliable to interpret, which gives possibility to obtain information about environmental situation, define sources of negative impacts and develop activities for relevant consequences mitigation.

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