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URBOECOSYSTEM ECOLOGICAL STATUS ASSESSMENT BY THE MORPHOLOGICAL PARAMETERS OF *PICEA ABIES* L. (ON THE EXAMPLE OF IVANO-FRANKIVSK CITY)

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The bioindicative prospects of Picea abies L. *in the conditions of an urbanized environment are analyzed based on the complex of morphological parameters of the species' vitality. The preference of conifers as phytoindicators of populated areas is substantiated due to the peculiarities of their physiology and structure. Simple, convenient and informative phytoindicative morphological markers of Picea abies vitality are applied: weight, length and type and degree of needle necrosis, as well as the general sanitary condition of the species individuals. The use of morphological indicators of coniferous plants vitality is proposed as an alternative to physiological and biochemical methods of biomonitoring, or analytical methods of ecological monitoring of the urban environment.*

The research is conducted in the conditions of functional zones of Ivano-Frankivsk city, selected on the principle basis of urban areas functional zoning. A decrease in the needles mass in the conditions of the transport routes zone and residential development zone is established by 1.9 and 1.6 times, relative to the background values, respectively. At the same time, the length of needles is a constant parameter and does not undergo a significant decrease compared to the background area. In the conditions of the urban ecosystem of Ivano-Frankivsk a decrease in the functional state of Picea abies individuals is observed in the following series of functional zones: background zone → zone of complex greening → zone of residential development → zone of transport routes. The highest necrosis degree of Picea abies needles is observed in the zone of the city's transport routes, while the dominant type of necrosis is apical. This is a sign of the heavy metals accumulation and other anthropogenic pollutants at the tips of the needles, which is an adaptive mechanism in response to stress. In the conditions of the Ivano-Frankivsk ecosystem the most common degree of necrosis of Picea abies needles is the first and fifth degrees. At the same time, the highest percentage of needles with signs of drying is observed in the transport routes zone of the city - 39%. In the area of complex greening and residential development this parameter is approximately 20%, and in the background area - 2%. The first class of damage refers to individuals of Picea abies growing in the complex greening zone, the second class of damage is observed in individuals existing in the residential development zone, and the third class of damage is fixed in individuals existing in the transport route zone of Ivano-Frankivsk city.

Picea abies is a promising biological indicator of the urban environment quality and is recommended for wider implementation in the practice of greening urban ecosystems.

Key words: Picea abies L., *urbanized environment, bioindication, anthropogenic pollution, morphological indicators*

Introduction. One of the most promising biological indicators are plant organisms that play the role of primary absorbers of anthropogenic pollutants, reacting accordingly with a complex of external visible changes and internal physiological and biochemical processes. At the same time, coniferous species are characterized by a number of advantages in terms of phytoindication over other plants, as they can be used to assess the quality of the environment all year round. Evergreen plants have much wider phytomelioration features and show a higher sensitivity to stress effects, compared to other plants (Andrea Rebeka Zsigmond et al., 2021; Cetin, Cobanoglu, 2019; Chung et al., 2021; Fedoniuk et al., 2021; Novakova et al., 2021; Navratil et al., 2019). *Picea abies* L. is one of the most common types of coniferous plants in Ukraine and is widely used in greening of urban ecosystems (Falvai et al., 2021; Fedorchak, 2020; Firas et al., 2020; Zitkova et al., 2021). The species is a well-known medicinal, vitamin and decorative plant. The use of convenient morphological parameters of the life state changes of the species allows timely response to the adverse environmental state and does not require significant material or human resources. The morphological reactions of plants are a reflection of internal metabolic changes in the body, the nature and features of which can be used to judge the life state of a particular species in the given conditions of existence (Hegrova et al., 2022; Huhu Kang et al., 2019; Mendez-Lopez et al., 2022; Swiercz et al., 2022). The most informative morphological parameters of the life state of conifers include indicators of growth and development, as well as the presence of necrotic damage to the assimilation organs (Nicoleta Ianovici et al., 2020). The classic reactions of a plant to a stressful effect are a decrease in the mass of individual organs and

the plant as a whole, as well as the appearance of various changes in the color of the needles. Therefore, the goal of our work is to assess the life state of *Picea abies* in the conditions of different functional zones of Ivano-Frankivsk city and to analyze the phytoindicative prospects of the species in the given conditions of existence.

Materials and methods. The research was conducted in the urban ecosystem of Ivano-Frankivsk, which is located in the southwest of Ukraine and is characterized by a fairly high development of the road network. Within the city limits, the following functional zones are identified: the zone of transport routes, the zone of residential development, and the zone of complex greening. The Demyaniv Laz tract, located on the northeastern outskirts of the city, is chosen as the background area. Within each zone, plant material is selected from 8-10 individuals of *Picea abies* from shoots of the first year of life along the perimeter of the crown at a height of 1.5 m at the end of the spring season (May).

The presence of necrotic lesions of *Picea abies* needles is determined visually. The classification of detected needle lesions types is carried out according to the methodology of S. S. Rudenko (Rudenko et al., 2008). The degree of damage is assessed on a 5-point rating scale: 0 - no damage; 1 - minor point necrosis is present; 2 - spotted necrosis up to 10 mm present; 3 - local necrotic spots that exceed 10 mm present; 4 - less than half of the conifer has died; 5 - the greater half of the conifer has died. For the analysis of necrosis, the selected needles are divided into three parts: undamaged needles, needles with spots, and needles with signs of drying. The length of 100 conifers needles is determined, as well as the mass of 1000 needles within each functional zone. The sanitary condition of *Picea abies* is determined using the recommended author's rating scale (table 1).

Table 1.

Scale for evaluating the sanitary condition of conifers

Level of defoliation	**Damage classes of conifers plants at different levels of needle color change, %**		
	<25	**25-60**	**>60**
0-10	0	I	II
10-20-25	I	II	II
20-25-60	II	II	III
>60	III	III	III
Non-viable tree	IV	IV	IV

Note. - Damage classes: 0 – healthy tree; I – light damage level; II – moderate damage level; III – severe damage level; IV – non-viable tree.*

Mathematical processing of the results is carried out using the variational statistical method. The reliability of the difference between the obtained experimental data and the background data is evaluated using the Student's t-test. The null hypothesis is rejected at $P \leq 0.05$. If the level of significance is in the range of $0.10 > P > 0.05$, then it is considered that there is a tendency for the manifestation of one or another process. All calculations are performed using the MS Excel 2007 editor and the Statistica 6.0 software package.

Results and their discussion. Among all stages of necrotization of *Picea abies* needles, the first stage takes the largest share in the conditions of a residential development zone - 37% (table 2).

Necrotization of the species needles increases in the following number of functional zones of the city: background zone (11%) → zone of complex greening (49%) → zone of residential development (62%) → zone of transport routes (94%). The most common degree of *Picea abies* needle necrosis in city conditions is the first and fifth degree, and the least common is the second degree of needle necrosis. Among all functional zones of the city, the zone of transport routes is characterized by the maximum fifth degree of *Picea abies* needles necrosis, which is about 54%.

Needles necrotic lesions are divided into the following types: apical, marginal and spotted (Rudenko, 2008). The apical and marginal types of necrosis occur as a result of heavy metals accumulation at the edges of the plants assimilation organs, which leads to the chlorophyll destruction by metals and the appearance of dead needle tissues. Heavy metals that enter plants from traffic pollution block biosynthetic processes in plant cells, which leads to their premature aging. According to literature data, *Picea abies* needles mostly accumulate Nickel and Ferrum, the branches of the species accumulate Chromium and Cuprum, and the stem accumulates Cadmium (Miri et al., 2017; Węgiel et al., 2018).

Table 2.

Picea abies needles necrosis degrees in the conditions of the functional zones of the Ivano-Frankivsk urban ecosystem

Functional zone	Degrees of necrosis, % of the needles total number				
	I	II	III	IV	V
Transport routes zone	3	7	15	15	54
Complex greening zone	19	10	8	9	3
Residential development zone	37	8	8	5	4
Background zone	5	3	3	0	0

The spotted type of needles necrosis occurs as a result of acid rain falling on the trees surface. Acid rain is the result of sulfur and nitrogen compounds entering the environment from the combustion of fuel in vehicles and oil refineries. Atmospheric precipitation with a pH of ≤5.6 is considered acidic and, upon contact with plants, causes burning of needle tissue.

Necrotic lesions of *Picea abies* bark are highlighted in the works of the following scientists (Chrzan, 2015; Terhonen, 2019; Blumenstein, 2021), and indicate the infection of plants with pathogenic fungi, which also affect young plants and can be the cause of mass infection of other plants species (Alizadeh, 2022).

In the conditions of Ivano-Frankivsk city *Picea abies* needles apical type of necrotic lesion dominates, which indicates the accumulation of heavy metals on the needles edges with their subsequent death (table 3).

The apical type of needle necrosis prevails in the area of the city's transport routes (48%). The marginal type of needle necrosis is the least common, and the spotted type occupies an intermediate position. The predominance of apical and marginal types of *Picea abies* needles necrotic lesions in the transport routes zone indicates the active entry of heavy metals into the species assimilation organs as a result of the combustion of fuel during the vehicles movement.

The presence of *Picea abies* needles necrotic lesions in the city indicates that acid rain is falling almost throughout the city, but at the same time dominating in the zone of transport routes. This is due to the combination of a significant amount of sulfur and nitrogen compounds, entering the environment during the combustion of motor vehicle fuel, with atmospheric moisture to form acid solutions of various concentrations.

Table 3.

Picea abies necrosis types of needles in the conditions of the functional zones of the Ivano-Frankivsk urban ecosystem

Functional zone	Type of necrosis, % of the total needles number		
	Marginal	Spotted	Apical
Transport routes zone	11	35	48
Complex greening zone	8	16	25
Residential development zone	9	18	35
Background zone	6	2	3

In the conditions of Ivano-Frankivsk city there is no significant decrease in needle length compared to the background area (table 4). The mass of *Picea abies* needles is significantly reduced by 1.6 and 1.9 times in the zone of residential development and the zone of transport routes, respectively, compared to the background values.

In the zone of the urban ecosystem transport routes the highest percentage of needles with spots and with signs of drying is observed - 48% and 39%, respectively. The lowest percentage of needles with spots and with signs of drying is observed in the background area - 3% and 2%, respectively. *Picea abies* individuls, growing in the conditions of the complex greening zone, are characterized by light damage level of the needles - the first class of damage. For the zone of residential development, the moderate damage of needles is noted, and for the zone of transport routes - severe damage of needles is observed (table 5).

Table 4.

Mass and length of Picea abies needles in the conditions of the functional zones of the Ivano-Frankivsk urban ecosystem

Functional zone	**Needles length, sm**	**Needles mass, g**
Transport routes zone	2,55±0,16	1,65±0,07*
Complex greening zone	3,10±0,18	2,47±0,11
Residential development zone	2,88±0,15	1,86±0,15*
Background zone	3,54±0,18	3,06±0,17

*Note: * - the value is significantly different from control*

Table 5.

Classification of needles types and sanitary state of Picea abies in the conditions of the functional zones of the Ivano-Frankivsk urban ecosystem

Functional zone	**% of needles**			**Class of damage**
	Undamaged	**Spotted**	**Non-viable**	
Transport routes zone	13%	48%	39%	III
Complex greening zone	56%	23%	21%	I
Residential development zone	44%	36%	20 %	II
Background zone	95%	3%	2%	0

Conclusions. In the conditions of Ivano-Frankivsk city the deterioration of *Picea abies* vitality is noted in the following series of functional zones: background zone → zone of complex greening → zone of residential construction → zone of transport routes. Individuals of *Picea abies* are characterized by light damage of the assimilation system in the zone of complex landscaping, moderate damage in the zone of residential development, and severe damage in the zone of transport routes. The highest percentage of needle necrosis and the greatest decrease in the mass of species needles is noted in the zone of the city's transport routes. The length of *Picea abies* needles in functional zones does not differ significantly from background values. In general, the *Picea abies* reacts sensitively to the anthropogenic loading of the city and can be successfully used as a biological indicator of the ecological state of the urban environment. The mass of *Picea abies* needles is the most sensitive morphological parameter of the species to the influence of heavy metals, and the type of needle necrosis and the sanitary condition of *Picea abies* should be used as informative bioindicative parameters of complex anthropogenic pressure of urban ecosystems, in particular, heavy metals and acid oxides in the form of precipitation

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ОЦІНКА ЕКОЛОГІЧНОГО СТАНУ УРБОЕКОСИСТЕМИ ЗА МОРФОЛОГІЧНИМИ ПАРАМЕТРАМИ *PICEA ABIES* L. (НА ПРИКЛАДІ МІСТА ІВАНО-ФРАНКІВСЬКА)

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Проаналізовано біоіндикаційну перспективність Picea abies L. в умовах урбанізованого середовища за комплексом морфологічних показників життєвості виду. Обґрунтовано перевагу хвойних порід як фітоіндикаторів урбанізованих територій з огляду на особливості їх фізіології та будови. Застосовано прості, зручні та інформативні фітоіндикаційні морфологічні маркери життєвості Picea abies: масу, довжину та тип і ступінь некрозу хвої, а також загальний санітарний стан особин виду. Запропоновано використання морфологічних показників життєвості хвойних рослин як альтернативу фізіолого-біохімічним методам біомоніторингу або аналітичним методам екологічного моніторингу міського середовища.

Дослідження проведено в умовах функціональних зон міста Івано-Франківська, виділених за принципом функціонального зонування міських територій. Встановлено зменшення маси хвої в умовах зони транспортних шляхів та зони житлової забудови у 1,9 та 1,6 рази відносно фонових значень, відповідно. При цьому довжина хвої є постійним параметром і не зазнає суттєвого зниження порівняно з фоновим значенням. В умовах урбоекосистеми Івано-Франківська спостерігається зниження функціонального стану особин Picea abies у ряді функціональних зон: фонова зона → зона комплексного озеленення → зона житлової забудови → зона транспортних шляхів. Найвищий ступінь некрозу хвої Picea abies спостерігається в зоні транспортних шляхів міста, домінуючим типом некрозу є верхівковий. Це ознака накопичення важких металів та інших антропогенних забруднювачів на кінчиках хвоїнок, що є адаптивним механізмом у відповідь на стрес. В умовах Івано-Франківської екосистеми найбільш поширеним ступенем некрозу хвої Picea abies є I та V ступені. При цьому найбільший відсоток хвої з ознаками всихання спостерігається в зоні транспортних шляхів міста – 39%. У зоні комплексного озеленення та житлової забудови цей показник становить приблизно 20%, а у фоновій зоні – 2%. До першого класу ураження відносяться особини Picea abies, що ростуть у зоні комплексного озеленення, до другого класу – особини, що існують в зоні житлової забудови, до третього класу – особини, що існують в зоні транспортних шляхів Івано-Франківська.

Picea abies є перспективним біологічним індикатором якості міського середовища і рекомендований для більш широкого впровадження в практику озеленення міських екосистем.

Ключові слова: Picea abies L.*, урбанізоване середовище, біоіндикація, антропогенне забруднення, морфологічні показники.*

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