The use of *Tilia cordata* Mill. as bioindicator for the evaluation of the ecological state of Kyiv urbanized areas (Ukraine)

Vitaliy B. Nebesnyi, Anna A. Grodzinskaya, Anna Yu. Gonchar, Sergiy M. Konyakin, Konstantin Yu. Schur

Abstract
For rapid assessment of the state of urban ecosystem was used a remote sensing spectrophotometric method. The method is based on the measurement of the spectral reflection characteristics of leaves of bioindicator species *Tilia cordata* Mill. According to the results of measurements an index of stress (reverse vegetation index) was calculated, as the most informative measure of the degree of suppression of photosynthesis and indirectly determines the level of anthropogenic contamination of the territory. In terms of the stress index with the use of cluster analysis performed grouping of 36 localities of the 10 administrative districts of Kyiv (the capital of Ukraine). A clear trend of growth of the index of stress values on a gradient of increasing the intensity of traffic flows was defined. This method is recommended for ecological monitoring of environmental quality, and rapid assessment of changes in urban ecosystems.

Keywords: *Tilia cordata* Mill., bioindication, spectral reflection, index of stress, urban ecosystem

Introduction
Solving actual environmental problems associated with the global decline in air quality, a significant increase of toxic emissions by industrial objects, enhancement loads from automobile transport requires continuous monitoring of environmental quality assessment[1,2]. Plants are reliable bioindicators of ecological condition of natural and urban ecosystems. The high degree of negative factors inherent to urban areas leads to weakening of plant organisms, premature senescence; reduce productivity, damage to diseases, pests and death of vegetation [3]. Urban areas is characteristic with specific environmental conditions, anthropogenic influences, leading to significant environmental transformation. Phytotoxic indicators is widely used for the evaluation of environmental contamination with toxic substances because they are forced to adapt to stress through physiological, biochemical and anatomical and morphological alterations of the body. Registration and evaluation of these changes, which may be recorded at an early stage of degradation, give an authentic picture the plant growth location and reflect the actual state of the urban environment [4, 5, 6, 7, 8]. Number of ecologically clean areas and parks within the city and the surrounding territories, steadily decreases and they become more and more valuables [9]. The most common and dangerous for the ecological state of soil and water of urban areas is a heavy metals pollution. It is known that the high concentrations of heavy metal salts in soils often leads to death of the plant communities [10]. Another one consequence of air and soil pollution is a change of plant pigments, in turn, appears to change of spectral reflection peculiarities, that allow using it for bioindication [11, 12]. Based on changes in the spectral reflective characteristics of the vegetation a method of remote sensing diagnosis of ecosystems had developed [11, 13]. The aim of present study was to evaluate the state of technogenic pollution of Kyiv (the capital of Ukraine) for the analysis of changes in the spectral reflectant characteristics of leaves of bioindicator species *Tilia cordata* Mill., which is widely used in planting of greenery of European cities.

Materials and methods
Spectrophotometric method, based on measurement of the biological responses of plants, was used for integrated evaluation of technogenic impact [14].
Spectral reflective characteristics more than 1200 leaves of *T. cordata*, collected during 2014 - 2015 in 36 localities of 10 administrative districts of Kyiv (Fig 1.), were measured with a field spectrophotometer (PF-8).

**Fig 1:** Sampling sites in Kyiv (2014-2015)

<table>
<thead>
<tr>
<th>№</th>
<th>Place of sampling</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Height above sea level, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Arkhitektor Verbytskyi St., 6</td>
<td>50°24'44.8&quot;N</td>
<td>30°39'02.5&quot;E</td>
<td>101</td>
</tr>
<tr>
<td>2</td>
<td>Kharkiv Highway 180/21 (living area)</td>
<td>50°24'35.9&quot;N</td>
<td>30°40'06.7&quot;E</td>
<td>102</td>
</tr>
<tr>
<td>3</td>
<td>Kharkiv Highway, 129 (along the highway)</td>
<td>50°24'44.6&quot;N</td>
<td>30°39'58.8&quot;E</td>
<td>102</td>
</tr>
<tr>
<td>4</td>
<td>Bazhana Ave.( Lebedyne lake)</td>
<td>50°24'00.3&quot;N</td>
<td>30°38'30.9&quot;E</td>
<td>96</td>
</tr>
<tr>
<td>5</td>
<td>Borova St., 10</td>
<td>50°24'48.3&quot;N</td>
<td>30°40'13.2&quot;E</td>
<td>101</td>
</tr>
<tr>
<td>6</td>
<td>Dragomanova St., 17</td>
<td>50°24'33.4&quot;N</td>
<td>30°38'20.5&quot;E</td>
<td>106</td>
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<tr>
<td></td>
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<tr>
<td>7</td>
<td>Magnitogorska St., 1 (JSC&quot;Khimvolokno&quot;)</td>
<td>50°27'15.2&quot;N</td>
<td>30°38'25.6&quot;E</td>
<td>104</td>
</tr>
<tr>
<td>8</td>
<td>Zakrevs'koho St., 5-7</td>
<td>50°29'51.4&quot;N</td>
<td>30°35'37.5&quot;E</td>
<td>102</td>
</tr>
<tr>
<td>9</td>
<td>Maiakos'koho Ave., 18</td>
<td>50°30'21.6&quot;N</td>
<td>30°36'15.9&quot;E</td>
<td>99</td>
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<tr>
<td>10</td>
<td>Lunacharsky St., 2</td>
<td>50°27'11.9&quot;N</td>
<td>30°35'47.9&quot;E</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>Entuziastiv St., 7</td>
<td>50°26'08.5&quot;N</td>
<td>30°36'03.7&quot;E</td>
<td>100</td>
</tr>
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<tr>
<td>12</td>
<td>Metrologicna St., 4-12</td>
<td>50°21'08.6&quot;N</td>
<td>30°28'34.1&quot;E</td>
<td>190</td>
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<tr>
<td>13</td>
<td>Nauki Ave., 32</td>
<td>50°23'45.2&quot;N</td>
<td>30°31'54.3&quot;E</td>
<td>149</td>
</tr>
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<td>14</td>
<td>Holosiivskyi Ave., 88</td>
<td>50°23'30.9&quot;N</td>
<td>30°30'14.0&quot;E</td>
<td>151</td>
</tr>
<tr>
<td>15</td>
<td>Park &quot; Feofania&quot;</td>
<td>50°20'24.0&quot;N</td>
<td>30°29'13.4&quot;E</td>
<td>153</td>
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The method is based on the ability of the objects to selectively reflect radiation energy in their specific spectral regions. Spectral photometer ranges are selected so as to meet the basic physiological processes that occur in plants [15, 16, 17]. In order to analyze the state of plants and a suppression of photosynthesis degree we selected an index of stress (a reverse vegetation index), which characterize the state of plant and determine the degree of inhibition of photosynthesis and impairment of water balance in the tissues of the leaf [17]. Cluster analysis was performed by Ward’s method (1963).

**Results and discussion**

Numerous publications of the last decades devoted to use of different plant species for bioindication of air pollution in areas with heavy road traffic and high concentration of industrial facilities [20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30]. In particular, studies on reflecting changes in the spectral characteristics of T.cordata leaves with different degrees of necrotic lesions that were selected in four locations of Ghent (Belgium), presented in the publication of A.R. Khavaninzadeh et al. [26] showed a possibility the method for assessment of urban environment quality.

As the most informative indicator we have chosen the index of stress (reverse vegetation index), which characterize the state of the plant and determine the degree of inhibition of photosynthesis. For low values of IS the photosynthesis productivity is higher and, accordingly, in general, a state of the ecosystem is better. For monitoring were selected samples of T.cordata leaves from localities of the city with varying distances to heavy road traffic and high concentration of industrial facilities. The investigated localities with the index of stress grouped into 3 groups with subgroups:

- IS = R1 / R3,

Which numerically determines the state of plant, a degree of inhibition of photosynthesis and impairment of water balance in the tissues of the leaf [17]. Cluster analysis was performed by Ward’s method (1963).

**Pecherskyi district**

<table>
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<tr>
<th>No.</th>
<th>Suburb/Street</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Index</th>
</tr>
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<tr>
<td>16.</td>
<td>Druzhby Narodiv Blvd., 7</td>
<td>50°24'47.0&quot;N</td>
<td>30°31'56.5&quot;E</td>
<td>143</td>
</tr>
<tr>
<td>17.</td>
<td>Grushevskogo St., 6</td>
<td>50°26'58.8&quot;N</td>
<td>30°31'49.6&quot;E</td>
<td>175</td>
</tr>
<tr>
<td>18.</td>
<td>Martinsky Park</td>
<td>50°26'30.5&quot;N</td>
<td>30°32'22.8&quot;E</td>
<td>199</td>
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**Podilskyi district**

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<th>Index</th>
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</thead>
<tbody>
<tr>
<td>19.</td>
<td>Verkhniy Val St., 4-6</td>
<td>50°27'47.5&quot;N</td>
<td>30°30'30.4&quot;E</td>
<td>117</td>
</tr>
<tr>
<td>20.</td>
<td>Naberezno-Khreshchatyk St., 35 and Khryvya St., 50</td>
<td>50°28'13.1&quot;N</td>
<td>30°31'18.4&quot;E</td>
<td>102</td>
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<tr>
<td>21.</td>
<td>Pivnichno-Syrets'ka St., 49</td>
<td>50°29'12.4&quot;N</td>
<td>30°25'34.0&quot;E</td>
<td>170</td>
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**Shevchenkivskyi district**

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<th>Index</th>
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<tr>
<td>22.</td>
<td>Pushkin park</td>
<td>50°27'19.3&quot;N</td>
<td>30°27'16.8&quot;E</td>
<td>173</td>
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<tr>
<td>23.</td>
<td>Peremogi Ave., 4</td>
<td>50°26'51.5&quot;N</td>
<td>30°29'20.7&quot;E</td>
<td>129</td>
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<tr>
<td>24.</td>
<td>Khreshatyk St.(at the corner of Prorizna St.)</td>
<td>50°26'52.1&quot;N</td>
<td>30°31'18.8&quot;E</td>
<td>158</td>
</tr>
<tr>
<td>25.</td>
<td>Park «Nvyky»</td>
<td>50°27'34.1&quot;N</td>
<td>30°24'46.4&quot;E</td>
<td>181</td>
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<td>26.</td>
<td>Scherbakova St., 10</td>
<td>50°27'42.0&quot;N</td>
<td>30°24'21.6&quot;E</td>
<td>182</td>
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**Solomi'ans'kyi district**

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<td>27.</td>
<td>Ostrovs'kyi Park</td>
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<td>30°28'07.6&quot;E</td>
<td>182</td>
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<td>28.</td>
<td>Lypkivs'koho St., 38-40</td>
<td>50°25'56.2&quot;N</td>
<td>30°28'29.8&quot;E</td>
<td>177</td>
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<td>29.</td>
<td>Volhohrad's'ka St., 6A</td>
<td>50°25'41.8&quot;N</td>
<td>30°29'33.2&quot;E</td>
<td>187</td>
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<td>30.</td>
<td>Lobanovs'koho Ave. (Chervonozorianyi), 51</td>
<td>50°25'08.9&quot;N</td>
<td>30°28'30.9&quot;E</td>
<td>187</td>
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<td>31.</td>
<td>Povitroflots'kyi Ave., 52</td>
<td>50°25'25.9&quot;N</td>
<td>30°27'25.7&quot;E</td>
<td>185</td>
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<td>32.</td>
<td>Lepse Blvd., 8</td>
<td>50°26'46.4&quot;N</td>
<td>30°25'02.3&quot;E</td>
<td>192</td>
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**Sviatosynskyi district**

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<th>Longitude</th>
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<tr>
<td>33.</td>
<td>Akademika Palladina Ave., 32/34</td>
<td>50°27'57.5&quot;N</td>
<td>30°21'24.5&quot;E</td>
<td>167</td>
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**Obolons'kyi district**

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<th>Suburb/Street</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Index</th>
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<tbody>
<tr>
<td>34.</td>
<td>Heroi Dnipra St., 16B</td>
<td>50°31'12.1&quot;N</td>
<td>30°30'32.7&quot;E</td>
<td>102</td>
</tr>
<tr>
<td>35.</td>
<td>Moskovs'kyi Ave.</td>
<td>50°29'20.4&quot;N</td>
<td>30°30'29.6&quot;E</td>
<td>97</td>
</tr>
<tr>
<td>36.</td>
<td>Vyshhorods'ka St., 32/2</td>
<td>50°30'27.8&quot;N</td>
<td>30°27'03.6&quot;E</td>
<td>116</td>
</tr>
</tbody>
</table>
a strong contamination – the index of stress was in the range of 0.255 -0.230.
(1 subgroup – 0.255 – 0.247, 2 subgroup – 0.242 – 0.230);
a medium contamination - the index of stress was in the range of 0.225 – 0.184 (1 subgroup – 0.225 – 0.214, 2 subgroup – 0.203 – 0.184)
and low pollution (IS was in the range of 0.167 – 0.132).

Results of study have shown that localities with the most intense traffic load (and therefore the highest value of the index of stress), characterized by numerous congestions in the transport interchanges, which result in significant concentrations of harmful emissions after fuel combustion products. From the objects of the second subgroup should be allocated on the Grushevskogo Street where during the revolutionary events in beginning of 2014 was man-made pollution of environment by combustion products tires.

Among the objects with a medium level of pollution, Pushkin Park attracts attention. Before our research we considered it as a locality with potentially low anthropogenic load. However, the data obtained suggest a significant impact on investigated locality a proximity to Peremogi Ave. and the industrial zone of the plant "Bolshevik" (the IS - 0.216) on selected bioindicator (*T. cordata*).

A low level of anthropogenic load (IS were in the range of 0.167 to 0.132), as expected, usually recorded in the park areas of Kyiv (Park “Feofania”, Ostrovs’kyi Park, Park Partyzans’koi Slavy (Borova St.), Pivnichno-Syrets’ka St. (forest area) etc.

Thus, the results of the study of spectral reflective characteristics of *T. cordata* leaves showed a tendency of growth of the index of stress along a gradient of traffic intensity in the city of Kyiv. It must be noted that in localities with high levels of pollution there are also more necrotic and fungal lesions of leaves were observed (Fig 3).

However, despite the complex kind of anthropogenic pollution of urban ecosystems with a set of contaminants, *T. cordata* is quite stable, which indicates its high adaptive capacity.

For the distribution of localities with the index of stress that determine the level of anthropogenic contamination, in addition the analysis of variance to assess the distance between clusters was applied [31] (Fig 4).

Fig 3: Necrotic lesions of *Tilia cordata* leaves (Lypkivs'koho St., 09 September, 2015.)

Fig 4: Dendrogram of similarity of *T.cordata* localities with the index of stress in 2014-2015
The combination of two-years data by cluster analysis allowed us to obtain two separate large clusters, i.e., in this case the ecosystem of the Kyiv city can be represented by two groups – average and significant levels of anthropogenic activity. These groups, in turn, bring together three subgroups, respectively (Fig 4).

The results convincingly demonstrate the overall high level of technogenic pollution of Kyiv. At the same time, a higher level of contamination and, accordingly, high levels of the index of stress were observed in the territory of districts located in the right-bank part of Kyiv. This phenomenon, in our opinion, in addition to the specific features of sources of pollution is also associated with differences in the geomorphological structure and micro-climatic conditions of the Kyiv city.

**Conclusion**

Study of the spectral reflection characteristics of bioindicator *T. cordata* has shown a trend of increasing of the index of stress along a gradient of traffic in Kyiv.

Bioindication of anthropogenic pollution of urban ecosystems for the spectral characteristics of leaves *T. cordata* is a promising low-cost method (in situ) of environmental monitoring.

The use of this method makes it possible to record on optical measurements and study stages of plant reactions to the action of natural and anthropogenic stressors, to diagnose an adaptation phase, a phase of stability and phase of excited irreversible changes, each of which has its own physiological mechanisms of suppression and patterns of accumulation of pollutants.

**References**


