ISSN 2320-3862
JMPS 2015; 4(3): 277-282

Received: 25-03-2016
Accepted: 28-04-2016

Vitaliy B. Nebesnyi
Institute for Evolutionary Ecology, NAS of Ukraine, Kyiv

Anna A. Grodzinskaya
A) Institute for Evolutionary Ecology, NAS of Ukraine, Kyiv
B) M.G. Kholodny Institute of Botany, NAS of Ukraine, Kyiv

Anna Yu. Gonchar
Institute for Evolutionary Ecology, NAS of Ukraine, Kyiv

Sergiy M. Konyakin
Institute for Evolutionary Ecology, NAS of Ukraine, Kyiv

Konstantin Yu. Schur
Institute for Evolutionary Ecology, NAS of Ukraine, Kyiv

Correspondence
Vitaliy B. Nebesnyi
Institute for Evolutionary Ecology, NAS of Ukraine, Kyiv

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.

Phytoindicators 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 reflectal 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)

Darnitskyi district

№	Place of sampling	Latitude	Longitude	Height above sea level, m
1.	Arkhitektor Verbytskyi St., 6	50°24'44.8"N	30°39'02.5"E	101
2.	Kharkiv Highway 180/21 (living area)	50°24'35.9"N	30°40'06.7"E	102
3.	Kharkiv Highway, 129 (along the highway)	50°24'44.6"N	30°39'58.8"E	102
4.	Bazhana Ave.(Lebedyne lake)	50°24'00.3"N	30°38'30.9"E	96
5.	Borova St., 10	50°24'48.3"N	30°40'13.2"E	101
6.	Dragomanova St., 17	50°24'33.4"N	30°38'20.5"E	106

Desnyanskyi district

7.	Magnitogorska St., 1 (JSC"Khimvolokno")	50°27'15.2"N	30°38'25.6"E	104
8.	Zakrevs'koho St., 5-7	50°29'51.4"N	30°35'37.5"E	102
9.	Maiakovs'koho Ave., 18	50°30'21.6"N	30°36'15.9"E	99

Dniprovskyi district

10.	Lunacharsky St., 2	50°27'11.9"N	30°35'47.9"E	100
11.	Entuziastiv St., 7	50°26'08.5"N	30°36'03.7"E	100

Holosiivskyi district

12.	Metrologichna St., 4–12	50°21'08.6"N	30°28'34.1"E	190
13.	Nauki Ave., 32	50°23'45.2"N	30°31'54.3"E	149
14.	Holosiivskyi Ave., 88	50°23'30.9"N	30°30'14.0"E	151
15.	Park " Feofania"	50°20'24.0"N	30°29'13.4"E	153

Pecherskyi district

16.	Druzhby Narodiv Blvd., 7	50°24'47.0"N	30°31'56.5"E	143
17.	Grushevskogo St., 6	50°26'58.8"N	30°31'49.6"E	175
18.	Mariinsky Park	50°26'50.5"N	30°32'22.8"E	199

Podilskyi district

19.	Verkhniy Val St., 4-6	50°27'47.5"N	30°30'30.4"E	117
20.	Naberezhno-Khreschatytska St., 35 and Khoryva St., 50	50°28'13.1"N	30°31'18.4"E	102
21.	Pivnichno-Syrets'ka St., 49	50°29'12.4"N	30°25'34.0"E	170

Shevchenkivskyi district

22.	Pushkin park	50°27'19.3"N	30°27'16.8"E	173
23.	Peremogi Ave., 4	50°26'51.5"N	30°29'20.7"E	129
24.	Khreschatyk St.(at the corner of Prorizna St.)	50°26'52.1"N	30°31'18.8"E	158
25.	Park «Nyvky»	50°27'34.1"N	30°24'46.4"E	181
26.	Scherbakova St., 10	50°27'42.0"N	30°24'21.6"E	182

Solom'ians'kyi district

27.	Ostrovs'kyi Park	50°25'46.9"N	30°28'07.6"E	182
28.	Lypkivs'koho St., 38-40	50°25'56.2"N	30°28'28.9"E	177
29.	Volhohrads'ka St., 6A	50°25'41.8"N	30°29'33.2"E	187
30.	Lobanovs'koho Ave. (Chervonozorianyi), 51	50°25'08.9"N	30°28'30.9"E	187
31.	Povitroflots'kyi Ave., 52	50°25'25.9"N	30°27'27.5"E	185
32.	Lepse Blvd., 8	50°26'46.4"N	30°25'02.3"E	192

Sviatoshyns'kyi district

33.	Akademika Palladina Ave., 32/34	50°27'57.5"N	30°21'24.5"E	167

Obolons'kyi district

34.	Heroiv Dnipra St., 16B	50°31'12.1"N	30°29'32.7"E	102
35.	Moskovs'kyi Ave.	50°29'20.4"N	30°30'29.6"E	97
36.	Vyshhorods'ka St., 32/2	50°30'27.8"N	30°27'03.6"E	116

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). In fact today there are about 160 different vegetation indexes [18]. They were chosen experimentally (empirically) on the base of the known spectral curves peculiarities of vegetation and soil reflectivity. Especially, the calculation of the vegetation indexes based on some of the most stable, not depended of other factors, the spectral curve parts of an reflective plants capacity. In the range of red zone (620-750 nm) are the absorption maximum of solar radiation by chlorophyll, in the range of green zone (550 nm) the reflection associated with the pigment composition of leaf, and near infrared (750-1300 nm) – the maximum reflection energy of leaf's cell structure. The literature data confirmed that a high photosynthesis activity, associated as usual with an increasing of phytomass, leads to a lower reflection coefficients in the red zone of the spectrum and a great value in the near infrared. The ratio of these parameters to let clearly separate the vegetation from other natural objects [18, 19].

The spectral reflection coefficients (SRC) of *T. cordata* leaves were measured in green - R1 (551.9 nm), red - R2 (656.8 nm) and near infrared - R3 (802.0 nm) range of spectrum.

The measured coefficients of reflection in these spectral bands ranging from 0 to 1. The measurement error was about 2.3 %. The index of stress was defined on the base of measurements as:

$IS = R1 / R3$,

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).

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 intensity of anthropogenic activity. Generalization of data of the index of stress (during 2014 and 2015) are shown in Fig. 2. From the histogram it's evident that calculated index of stress increases in localities close to the motorway. The investigated localities with the index of stress grouped into 3 groups with subgroups :

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).

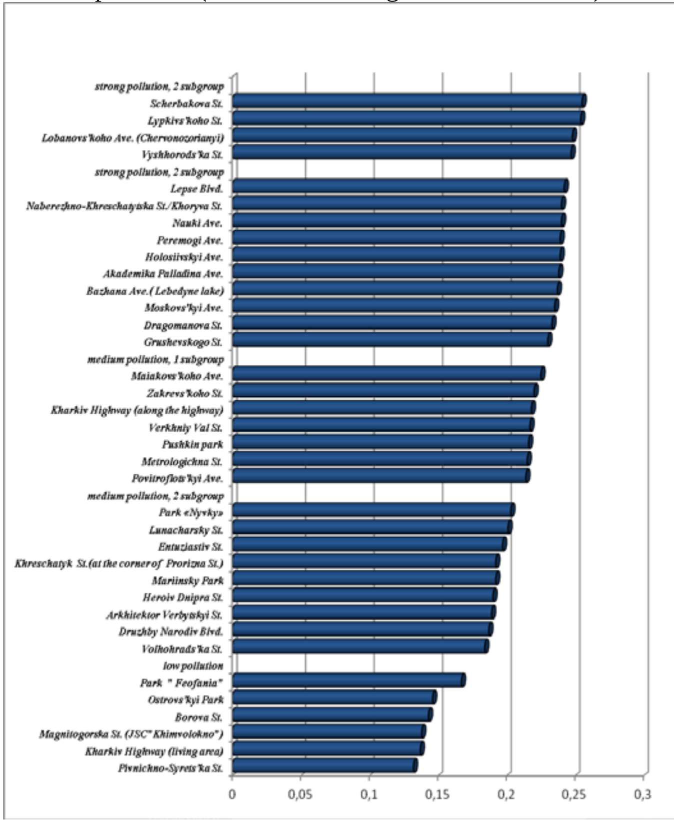

Fig 2: Grouping of anthropogenic impact of Kyiv city with the index of stress in 2014 and 2015.

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).

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

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).

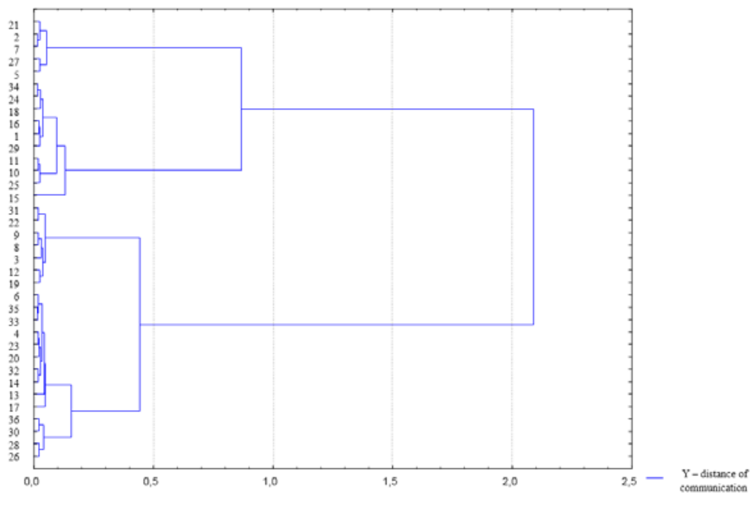

Fig 4: Dendrogram of similarity of *T.cordata* localities with the index of stress in 2014-2015

The combination of two-years data by cluster analysis allowed us to obtain two separate large clusters, i.e., in this case urboecosystem of the Kyiv city can be represented by two groups – average and significant levels of anthropogenic activity. These groups, in turn, brings together three subgroups, respectively (Fig 4).
The results convincingly demonstrate the overall high level of 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

1. Falla J, Laval-Gilly P, Henryon M, Morlot D, Ferard J. Biological air quality monitoring: a review. Environ. Monit. Assess 2000; 64:627-644.
2. Cen S. Biological Monitoring of Air Pollutants and Its Influence on Human Beings. The Open Biomedical Engineering Journal. 2015; 9:219-223. Published online 2015 Aug 31. doi: 10.2174/1874120701509010219 PMCID: PMC4645973.
3. Kurgaeva AV. The use of fluctuating asymmetry to assess the ecological status of urban areas on the example of Ulyanovsk. Bioindication in ecological assessment of soils and related habitats. Proc. rep. Int. Conf. Moscow, 2013; 4-6:117 [in Russian].
4. Nicholaevskyi VS. Ecological assessment of environmental pollution and the state of terrestrial ecosystems with phytoindication methods. 1999, 193. [in Russian].
5. Maydebura IS. The influence of air pollution of Kaliningrad on the anatomical – morphological and biochemical indices of woody plants. Ph D Thesis for biol. Sci. Kaliningrad, 2006, 22. [in Russian].
6. Lutsyshyn OG, Radchenko VG, Palapa NV, Yavorovsky PP. Macromorphological change of response reaction of woody plant from street of Kiev metropolis stands at stress levels of anthropogenic pollution. Reports of NAS of Ukraine, 2010; 6:180-187. [in Ukrainian].
7. DiduhYa P. Basics of bioindication. K.: NaukovaDumka, 2012, 344. [in Ukrainian].
8. Nebesnyi VB, Grodzinskaya AA. Assessment of technogenic pollution of Kyiv (Ukraine) with spectral reflectal characteristics of *Tilia cordata* Mill. (Tiliaceae) leaves. Environmental and Socio-economic Studies, 2014; 2(4):38-42.
9. Andreeva AV, Buznikov AA, Timofeev AA, Alekseeva-Popova NV, Belyaeva AI. Evaluation of the ecological state of environment with a reflection spectruma of indicator species of vegetation. Actual Problems of Remote Sensing of the Earth from Space: physical bases, methods and technologies for monitoring of environment, potentially dangerous phenomena and objects. Coll. scientific articles, 2006; II(3):265-270. [in Russian].
10. Artamonov VI. Plants and purity of the natural environment. M. Nauka, 1986, 86. [in Russian].
11. Andreeva AV, Buznikov AA, Timofeev AA, Scriabin SV. Spectral studies of anthropogenic impact on vegetation of megapolisis. News of St.-Petersburg ETU LETI, 2006; 1:31-38. [in Russian].
12. Andreev DN. Bioindication of environment with a chlorophyll fluorescence of needles of Scots pine. Bioindication in ecological assessment of soils and related habitats. Proc. rep. Int. Conf. Moscow, 2013; 4-6:12. [in Russian].
13. Andreeva AV, Buznikov AA, Scriabin SV, Timofeev AA, Alekseeva Popova NV, Belyaeva AI. Investigation of the nature of changes in the optical characteristics of the vegetation under the influence of heavy metals for the development of diagnostics pollution method. Actual Problems of Remote Sensing of the Earth from Space, 2007; II(4):175-182 [in Russian].
14. Levanchuk AV, Kopytenkova OI, Nehoroshev AS, Gayko II. Method of monitoring of habitat quality in the city. Successes of actual sci. 2005; 9:59-61. [in Russian].
15. Kondrat'ev KYa, Fedchenko PP. The spectral reflectance and recognition of vegetation. L: Gidrometeoizdat, 1982, 216. [inRussian].
16. Surin VG. Field precision photometry method for interpretation of geochemical anomalies. Investigat. of Earth from Space, 1998; 4:38-44. [in Russian].
17. Surin VG. Active optical testers for information providing for precision agriculture, animal husbandry and environmental safety. Agrophysics, 2011; 2:39-49. [in Russian].
18. Cherepanov AS, Druzhinina EG. Spectral properties of plants and vegetation indices. Geomatics, 2009; 3:28-32. [in Russian].
19. Motohka T, Nasahara KN, Oguma H, Tsuchida S. Applicability of Green-Red Vegetation Index for Remote Sensing of Vegetation Phenology. Remote Sensing, 2010; 2:2369-2387.
20. Gonzalez SM, Casanovas SS, Pignata ML. Biomonitoring of air pollutants from traffic and industries employing Ramalina ecklonii (Spreng.) Mey. And Flot. in Cordoba, Argentina. Environ. Pollut. 1996; 91:269-277.
21. Kammerbauer J, Dick T. Monitoring of urban traffic emissions using some physiological indicators in *Ricinus communis* L. Plants. Arch. Environ. Contam. Toxicol, 2000; 39:161-166.
22. Klumpp A, Wolfgang A, Klumpp G, Calatayud V, Garrecc JP, He S *et al.* Ozone pollution and ozone bio-monitoring in European cities Ozone concentrations and cumulative exposure indices at urban and suburban sites. Atmos. Environ, 2006; 40:7963-7974.
23. Wuytack T, Verheyen K, Wuyts K, Kardel F, Adriaenssens S, Samson R. The potential of biomonitoring of air quality using leaf characteristics of white willow (Salix alba L.). Environ. Monit. Assess, 2010; 171:197-204.

24. Khavaninzadeh AR, Veroustraete F, Wuyts K, Kardel F, Samson R. Dorsi- ventral leaf reflectance properties of *Carpinus betulus* L.: an indicator of urban habitat quality. Environ. Pollut 2012; 162:332-337.
25. Khavaninzadeh AR, Veroustraete F, Buytaert JAN, Dirckx J, Samson R. Assessing urban habitat quality using spectral characteristics of Tilia leaves. Environ. Pollut, 2013; 178:7-14. http://dx.doi.org/10.1016/j.envpol.2013.02.021.
26. Khavaninzadeh AR, Veroustraete F, Buytaert JAN, Samson R. Leaf injury symptoms of *Tilia* sp. as an indicator of urban habitat quality. Ecological indicators, 2014; 41:58-64.
27. Kardel F, Wuyts K, Khavaninzadeh AR, Wuytack T, De Smedt S, Babanezhad M *et al.* Comparison of leaf saturation isothermal remanent magnetisation (SIRM) with anatomical, morphological and physiological tree leaf characteristics for assessing urban habitat quality. Environ. Pollut 2013; 183:96-103.
28. Sifakis N, Soulakellis NA, Paronis DK. Quantitative mapping of air pollution density using earth observations: a new processing method and application to an urban area. International Journal of Remote Sensing. 1998; 19:3289-3300.
29. Retalis A, Cartalis C, Athanassiou E. Assessment of the distribution of aerosols in the Athens with the use of Landsat Thematic Mapper data. International Journal of Remote Sensing. 1999; 20(5):939-945.
30. Nebesnyi VB, Grodzinskaya AA. An assessment of industrial pollution of Kyiv with the spectral reflection of *Tilia cordata* (Tiliaceae) leaves. Ukr. Bot. J, 2015; 72(2):116-121. [in Ukrainian].
31. Ward JH. Hierarchical grouping to optimize an objective function. Journal of the American statistical association. 1963; 58(301):236-244.