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Environmental sustainability and phytomelioration suitability of woody plants in urban ecosystems

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The problem of trees selection in urban green spaces is reviewed. Environmental sustainability and phytomelioration ability of the dominant representatives of the most spread woody plants types used in urban landscaping is analyzed. The criteria for assessing the vitality of plants at different levels of biosystem organization are accented; key parameters of adapted species protective processes and destructive parameters of unstable species in stressful growing conditions are highlighted. The use of resistant to anthropogenic pollution species of *Salix* L. genus as effective phytoremediants of technologically-transformed ecosystems is proposed. Sensitive to environmental contamination *Aesculus* L. and *Pinus* L. species are not recommended for planting in urban areas. However, they can be used as informative bioindicators of environmental ecological condition. Middle resistant species of *Populus* L., *Tilia* L., *Betula* L., *Acer* L. genera are recommended to implementation in urban ecosystems greening of recreation areas – parks and squares. Sustainability of the trees genera analyzed in terms of anthropogenic pressure is increased in the following range: *Aesculus* L. → *Pinus* L. → *Populus* L. → *Tilia* L. → *Betula* L. → *Acer* L. → *Salix* L.

Key words: *environmental sustainability, phytomelioration suitability, woody plants, urban environment.*

Екологічна стійкість та фітомеліоративна придатність деревних порід урбанізованих екосистем

Н.Глібовицька

Розглянуто проблему добору деревних порід у зелених насадженнях міських екосистем. Проаналізовано екологічну стійкість та фітомеліоративну придатність домінуючих представників найпоширеніших родів деревних рослин, що використовуються в озелененні урбанізованих територій. Виділено критерії оцінки вітальності рослин на різних рівнях біосистемної організації, основні показники пристосувально-захисних процесів адаптованих видів та деструктивних параметрів нестійких видів у стресових умовах зростання. Запропоновано використовувати стійкі до антропогенного забруднення види роду Верба у якості ефективних фітомеліорантів техногенно-трансформованих екосистем. Чутливі до контамінації довкілля види роду Каштан та Сосна не рекомендуються для озеленення урбанізованих територій. Проте їх можна застосовувати як інформативні біоіндикатори екологічного стану навколишнього середовища. Середньостійкі види родів Тополя, Липа, Береза, Клен рекомендовано впроваджувати у озеленення відпочинкових зон міських екосистем – парків та скверів. Екологічна стійкість проаналізованих представників родів дерев в умовах антропогенного навантаження зростає у ряді: Каштан → Сосна → Тополя → Липа → Береза → Клен → Верба.

Ключові слова: *екологічна стійкість, фітомеліоративна придатність, деревні породи, урбосередовище.*

Экологическая устойчивость и фитомелиоративная пригодность древесных пород урбанизированных экосистем

Н.Глибовицкая

Рассмотрена проблема отбора древесных пород в зеленых насаждениях городских экосистем. Проанализированы экологическая устойчивость и фитомелиоративные пригодность доминирующих представителей самых распространенных родов древесных растений, используемых в озеленении урбанизированных территорий. Выделены критерии оценки витальности растений на разных уровнях биосистемной организации, основные показатели приспособительные-защитных процессов адаптированных видов и деструктивных параметров неустойчивых видов в стрессовых условиях роста. Предложено использовать устойчивые к антропогенному загрязнению виды рода Ива в качестве эффективных фитомелиорантив техногенно-трансформированных экосистем. Чувствительные к контаминации окружающей среды виды рода Каштан и Сосна не рекомендуются для озеленения урбанизированных территорий. Однако их можно применять как информативные биоиндикаторы экологического состояния окружающей среды. Среднестойкие виды родов Тополь, Липа, Береза, Клен рекомендуется внедрять в озеленение зон отдыха городских экосистем – парков и скверов. Экологическая устойчивость проанализированных представителей родов деревьев в условиях антропогенной нагрузки возрастает в ряду: Каштан → Сосна → Тополь → Липа → Береза → Клен → Верба.

Ключевые слова: *экологическая устойчивость, фитомелиоративная пригодность, древесные породы, урбосреда.*

Introduction

One of the main parameters of anthropogenic pressures that worsen urban and suburban areas condition is urbanization (Gnativ, 2003a; 2006; Mylenka, 2008; Burghardt et al., 2009; Cuiping, Zhiming, 2012; McKinney, 2006; McPherson et al., 2005; Williams et al., 2009). Woody plants that are used in cities' greenery are experiencing complex chronic technogenic impact of changed environmental factors and maintain natural cleansing role (Parpan, Mylenka, 2009; Evarte-Bundere et al., 2014; Jancevica, Zigmunde, 2013; Nowak et al., 2002; Pincetl, 2010; Rotherham, 2014; Streetheran et al., 2011; Sullivan et al., 2009).

The experience of foreign scientists (Derric et al., 2010; Kowarik, 2011; Kowarik et al., 2013; Millard, 2000; McKinney, 2006; Oldfield et al., 2013; Ordonez, Duinker, 2012; Pennington et al., 2010; Trammell, Carreiro, 2011) suggests that native woody plants species are more suitable than exotic species for populated areas' greenery, as they are more adapted to their growth conditions and more effectively use available resources.

According to the literature (Gnativ, 2002; Clarkson et al., 2012; Luvisi, Lorenzini, 2014; Pataki et al., 2011), the degree of the living organism resilience to the environment is characterized by its vitality as the ability to implement the genetic program of growth and development in specific existence conditions. The measures of environmental sustainability are dynamic, adaptive defense mechanisms. In the works of some scientists (Glibovytska, 2015; Gnativ, 2006; Kurnytska, 2003; Mylenka, 2009) it's stated that the vitality of organisms at different levels of biosystem organization may be different. This is because the damaging effects at lower levels are often eliminated at higher and therefore are not always visible through the reaction of organisms, although can play a significant role in genetic and reproductive processes in the remote period.

In the literature (Gnativ, 2002; Mylenka, 2009; Odukalets, 2011; Johnstone et al., 2013) the experience of assessment of plants vitality for complex of qualitative and quantitative parameters on molecular, organ, organismal and population levels of biosystem hierarchy is described. Thus, the vitality of plants is manifested in their ability to maintain the key physiological, biochemical, growth, reproductive processes in adverse environmental conditions.

The viability of populations, respectively, depends on the ratio of individuals of different vitality levels and manifests in the ability to retain reproductive function and to control population field (Hissovskyy, 2012).

According to the deviation of vital values from control parameters some scholars (Kurnytska, 2001) distinguish three vitality classes of urban trees – high, medium and low. Foreign scientists (Evarte-Bundere et al., 2014) proposed scale vitality of trees in urban areas, providing six vitality classes. We developed a scale that includes five vitality classes and can be used for urban tree species (Glibovytska, 2015).

According to the literature (Bessonova et al., 1996; Johnstone et al., 2013; Krumov et al., 2008; Kuklova et al., 2013; Zhang et al., 2013), the criteria to assess the stability of trees under anthropogenic stress conditions are:

- morphologic – the weight and linear parameters of vegetative and generative organs, the necrosis injuries, diseases and pests presence, the level of crown defoliation and dechromation;
- physiological – content and ratio of photosynthetic pigments, proline, metabolic leaf composition, acidity and buffering of leaf internal environment;
- cytogenetic – the presence and number of chromosomal aberrations and mitotic activity.

Thus, the problem of trees selection in urban plantings that have resistance to contamination and therefore high phytomelioration perspectives is still relevant.

Patterns of trees adaptation as a prerequisite for survival in urban environment

According to the literature (Gnativ, 2006; Gaffin et al., 2012), the plants of urban areas are characterized by ecological plasticity, serving as a mean of survival in a changing environment. Mechanisms of plant organism's adaptation to external conditions are formed in the process of historical development through appropriate changes of organs architectonics, life forms, modes of reproduction and distribution, types of metabolism under the action of specific factors (Gnativ, 2008).

In the plants adaptation to environmental conditions various physiological, biochemical, anatomical and morphological mechanisms are involved. At physiological and biochemical levels of study the sensitivity of living organisms to the stressors action is the highest and is regarded as one of the most informative vitality parameters (Yusypiva, 2012). Different species vary greatly in features and the depth of adaptive changes (Gnativ, 2003a).

The ability of internal protective mechanisms of living systems to resist against external stress influences, to adapt without significant structural and functional parameters changes or to return quickly to a stable state is called environmental sustainability (Gnativ, 2008). Total environmental organism resistance over time is called sustainability, which characterizes by normal development in specific conditions (Gnativ, 2003a). Adaptation is possible only if the body is able to demonstrate stability on any level – from the cell to the population level. Stability level is determined by the intensity of stressors action, speed and degree of deviation from the norm, the degree of biochemical, physiological and morphological adaptation (Gnativ, 2003b, 2006).

There are three types of plant resistance (Musienko, 1995):

- biological – is described by the plants ability to restore damaged organs that is common for the rapidly growing plants;
- morphological and anatomical – is marked by the decline of damages in plants assimilation organs by preventing toxic gases penetration in the body;
- physiological – is characterized by the soluble fraction of substances in the cell.

It is known that among the plants organs leaves show the highest ecological plasticity to anthropogenic factors (Gnativ, 2008). Their anatomical and morphological structure, assimilation organs variability can be a reliable means of assessing plants stability. Reliable criteria of plants adaptation to adverse environmental conditions are changing biochemical parameters. A common bioindication feature of any stressor impact on plant organisms is reducing the content of soluble proteins due to decrease in synthetic processes and increase in hydrolytic (Yusypiva, 2012). In the adaptation of plants to unfavorable factors the change in the number of free amino acids is important because of their direct connection with the metabolism of proteins (Gnativ, 2003b).

One of the primary metabolism links exposed to external stress factors, caused by anthropogenic pressure, is a photosynthetic system, which is formed by pigments, proteins, protein-lipid complexes concentrating in chloroplasts. Adaptation processes to stress factors depend primarily on the optimal functioning of the plant assimilation apparatus, the level of photosynthetic pigments is one of the main indicators (Mysiak, 2011). Plastid pigments concentration and their condition determine the resistance to adverse environmental factors, the viability and productivity of plants. In well-developed plants the chlorophyll biosynthesis process is more energetic than in weakened plants. Chlorophyll a and carotene are more sensitive to the pollutants effects than chlorophyll b. Therefore the ratio of chlorophyll a to chlorophyll b is changing in the direction to its decline (Kapeliush, 2012). Carotenoids provide plants tolerance to the impact of various environmental pollutants. These multifunctional pigments have a supporting role in photosynthesis, a protective function during oxidative stress, act as protection systems signals, activators of gene expression and processes leading to increasing plant resistance (Khvostov et al., 2011). Adapted species are marked by lower photosynthesis activity and a lower rate of pollutants absorption compared to non-adaptive (Yusypiva, 2014; Khvostov, Kapeliush, 2011). In unstable species environmental contamination causes the plastid pigments reduction and decreasing strength between chlorophylls and proteins (Mysiak, 2011).

Heavy metals are the main pollutants of urban ecosystems that, getting into the plant tissues, disorder a number of metabolic processes, block the synthesis of vital substances (Gnativ, Korshikov, 2006). Adaptive and protective mechanisms of plant cells in response to heavy metals penetration are the antioxidant enzymes – superoxide dismutase, catalase, glutathione transferase, glutathione reductase – activation, which perform protective function against free radicals generated during oxidative stress (Musienko, 1995). Another adaptive mechanism of plants is the formation of protective proteins stable complexes with heavy metals (Yusypiva, 2012; Inostroza-Blarchsteau, 2012; Turner et al., 1991).

One of the universal stress protector compounds in plants organism is the proline amino acid that maintains cellular homeostasis under adverse environmental conditions (Parpan, Mylenka, 2009).

According to the literature (Gnativ, 2010; Molotkovskyy, Zhestova, 1964), carbohydrate metabolism plays an important role in the adaptive reactions of plant organisms to environmental conditions. The amount of sugars and starches and their correlation index in the dry leaf mass gives the reliable information about plant response to specific growing conditions. The characteristic features of plants high adaptive capacity under stressful conditions are protein, soluble carbohydrates and starch content growth, lipids synthesis increasing on the background of fiber and nitrogen free extract concentration decrease (Gnativ, 2005).

Informative test for the detection of adaptive plants capacity is a pH value of green leaves homogenate, redox properties study and buffer stability of the internal organism environment (Gnativ, Artemovska, 2009).

On the organ level reducing the morphometric parameters is non-specific adaptive response of plants aimed to decrease the area of contact with the polluted environment, to optimize the water regime, to decrease costs of material and energy resources in the defense mechanisms restructuring (Glibovytska, 2015; Mylenka, 2009; Odukalets, 2011).

The woody plants life condition in urban ecosystems and greenery prospects

The most common in urban ecosystems green spaces are species of the *Populus* L. (Esenzholova, Panin, 2012; Bazzaz, 1996; Hauru et al., 2012; Lehvavirta, Rita, 2002; Loreto et al., 2014), *Betula* L. (Lovynska et al., 2013a; Gnativ, 2010; Bazzaz, 1996; Erofeeva, 2014; Hauru et al., 2012; Lehvavirta, Rita, 2002; Prach, 2003), *Salix* L. (Loreto et al., 2014), *Acer* L. (Bazzaz, 1996; Lehvavirta, Rita, 2002; Zipperer, 2002; Lovynska et al., 2013a), *Aesculus* L. (Lovynska et al., 2013a; Petrova et al., 2012), *Tilia* L. (Alekseev, Vinnichenko, 2012; Lovynska et al., 2013a; Erofeeva, 2014) and *Pinus* L. (Hauru et al., 2012; Kuklova et al., 2013) genera.

According to literature (Vishnjakov, 2009), deciduous trees are more resistant to environmental contamination than conifers, due to the annual leaves change that accumulate toxicants in the cuticle, epidermis and mesophyll. Under the influence of fluorine and chlorine in the environment a linear dimensions decrease, clogged arteries and tissue needles damages of *Pinus sylvestris* L. take place, namely deformation, discoloration, plastid pigments destruction (Dragan, 2008). Changes in morphological and anatomical needles structure, mainly the epidermis and mesophyll thickness reducing, the number needles stomata decreasing – is a result of prolonged exposure to small concentrations of nitrogen and sulfur compounds in the environment (Odukalets, 2011). Stressful growing conditions have a great influence on the conifers generative scope. This is manifested in reducing the pollen viability, seeds abnormalities and their quality (Tretyakova, Noskova, 2004).

Among conifers morphological abnormalities at organismal level of biosystem organization under urbanized environmental conditions are: inhibition of the main axis growth, branching complications, lateral meristems increased activity, branches, needles, stem wood weight decreasing, which are signs of premature aging (Vishnjakov, 2009). Because of pollutants entering the body, the protective lipid layer destruction occurs and needles area coated with wax decreases (Odukalets, 2011). At the molecular level a decrease in antioxidant levels leads to activation of lipid peroxidation and destruction of the pigment complex (Dragan, 2008).

In terms of urban ecosystems the inhibition of growth and development processes of *Tilia* L. species occurs. In particular, the reduction of leaf surface, vegetative organs length decrease, quantity and weight of the generative organs declension, phaenological rhythms abnormalities and accelerated aging are observed in plants growing in adverse conditions (Dzyuba, Tarasevich, 2001; Kapeliush, 2012; Lutsyshyn et al., 2010; Yusypiva, Korostylov, 2015; Erofeeva, 2014). Along with this there are visible signs of assimilation organs damages: necrosis as a result of metabolic processes abnormalities caused by pollutants, plastid pigments destruction and changes in enzyme systems activity (Alekseev, Vinnichenko, 2012; Zhytska, 2011; Sovakova et al., 2012).

We found that the content of chlorophyll and carotenoids in *Tilia cordata* Mill. leaves is lowered with increasing degree of urban environment transformation (Glibovytska, 2015). This woody plant is characterized by increased proportion of carotenoids in plastid pigments in stressful growth conditions that is a statement of the type’s adaptive responses. The dissimilation processes prevalence, including the concentration of starch, fiber and protein reducing, the leaves gradual buffer potency loss on a background of activation the synthesis of water-soluble carbohydrates and lipids in leaves of plants indicates species environmental sensitivity and flexibility (Glibovytska, 2015; Yusypiva, Smith, 2012). The high accumulative capacity of *Tilia cordata* Mill., including heavy metals absorption, dust accumulation and quick recovery after the crown trimming indicates the effective implementation of phytomeliorative function (Halyamova, 2013; Bragin et al., 2014; Mylenka, 2008; Ponomareva, Bessonova, 2012a).

According to the literature (Ponomareva, Bessonova, 2012b), *Tilia tomentosa* Mill., *Tilia platyphyllos* Scop. and *Tilia europeae* L. are the best to restore their crown after rejuvenate pruning. However under terms of unfavourable growing conditions species of *Tilia* L. genus are damaged by diseases and pests and reduce phytoncide activity (Volodarets, 2012).

The comprehensive study of the *Populus* L. genus vitality revealed the low adaptation level of the most common species – *Populus simonii* Carr., *Populus nigra* L., *Populus deltoides* Marsh., *Populus alba* L., *Populus berolidensis* Deep. in urban environment conditions. Adaptive mechanism found in *Populus pyramidalis* Roz. is the proline content increase in the leaves caused by urban stressors impact (Parpan, Mylenka, 2009). Markers of destructive species changes are reducing the organs mass and surface, presence of necrosis, diseases, tree trunks damages, vegetative organs growth loss and the value of annual shoot growth inhibition (Sluchyk, 2000). Anthropogenic contaminants inhibit mitotic activity of embryonic leaves, disturb normal cell mitosis phases division, increase the level of sterility, morphologic pollen differentiation, chromosomal aberrations (Mylenka, 2009). The male gametophyte is most sensitive to the anthropogenic factors influence (Sluchyk, 2000). With the growth of environmental pollution representatives of *Populus* L. genus decrease photosynthetic pigments concentration in assimilation organs, reduce the activity of antioxidant protection, increase destructive processes in general (Khromykh, 2012). However, the genus species are characterized by high heavy metals absorptive capacity and large bioindication availability of fluctuating asymmetry leaves parameter, which allows to use sensitive plants as bioindicators of environmental ecological condition (Ganzha, 2012).

The relatively well-studied species of the genus *Aesculus* L. – *Aesculus hippocastanum* L. is marked by low vitality level under the city stressful impact (Radchenko et al., 2010; Petrova et al., 2012). In stressful urban growth conditions in *Aesculus hippocastanum* leaves nitrogen free extracts concentration growth, lipid and fiber content reducing was found, which is a sign of plants hydrolytic processes strengthening (Gnativ, 2003a; 2010). Visual morphological type's reactions on urban pressure are leaf plates necrosis, growth processes inhibition, the massive damages by pests, including chestnut moth (*Cameraria ochridella* Deschka and Dimic), fungus *Nectria cinnabarina* Tode. (Hryhoryuk, 2004). According to the literature (Lutsyshyn et al., 2010; Radchenko et al., 2010), in mid-summer period *Aesculus hippocastanum* crown defoliation occurs because of assimilation system necrosis, leading to the death of drying branches and trees. This reveals about species environmental instability, low adaptive capacity and inability to maintain meliorative function in conditions of anthropogenic loading.

Researches of *Acer* L. genus species vitality indicate their medium adaptive ability to grow in urban environment. Specifically *Acer platanoides* L., *Acer negundo* L., *Acer pseudoplantanus* L. are marked by plastid pigments concentration decrease in leaves under the influence of polluted environment (Lovynska et al., 2013b). However, significant reduction of vegetative growth processes in plants is not found (Khvostov et al., 2011). According to the dry matter metabolic leaves composition the genus species are characterized by prevalence of catabolic processes in stressful growth conditions. It shows a decrease of total protein, starch, lipid content and increase of nitrogen free extract and disaccharides concentration (Gnativ, 2003a). Buffer stability of the internal leaves environment of maples is higher compared with the same parameter in limes. However maples worse tolerate the crown pruning and are more affected by pests and diseases. With the growth of anthropogenic pressure the maple leaf cover damages by fungal infection are observed (Lutsyshyn et al., 2010).

Species of *Salix* L. genus – *Salix alba* L. and *Salix caprea* L. are the most studied in terms of environmental adaptation. According to adaptive and protective changes at different levels of the biosystem organization the species are referred to resistant (Gnativ, 2008; Loreto et al., 2014). At a high level of heavy metals accumulation by plants assimilation organs of the species are characterized by increased synthesis of carotenoids acting as chlorophyll protectors from oxidation. At the molecular level in urban growing conditions takes place protein concentration grows, protector cell compounds – lipids, soluble carbohydrates concentration growth and fiber proportion reduction (Gnativ, 2010). The significant decrease in the size of species leaf plates under the influence of pollution is not found. *Salix* L. genus species are resistant to cytotoxic environmental factors. The significant increase in the amino acid proline concentration in vegetative plant's organs as a result of pollutants influence is not recorded, that is a sign of ecological tolerance (Mylenka, 2009).

The dominant tree species of the *Betula* L. genus in urban ecosystems plantations, *Betula pendula* Roth., refers to medium resistant (Gnativ, 2003a). Confirmation of this are typical adaptive and destructive morphological, physiological and biochemical changes in the body of plants that grow in urban areas. In particular, under the influence of urbogenic factors chlorophyll concentration is falling on the background of increased carotenoids concentrations, increased proline and total protein content in tissues (Blyusyuk, 2011). There is a significant reduction in the growth and development processes of the weakened plants (Zhytska, 2011; Mylenka, 2009; Erofeeva, 2014). According to the sensitivity of generative sphere to contaminants influence *Betula pendula* is intermediate between lime and maple. In urban conditions changes in phaenological phases terms and damages caused by pests are set (Kuklina, 2007).

According to the analyzed literature and studied complex of adaptive and destructive changes of plants in urban ecosystems the vitality of the most common trees is growing in a row: *Aesculus* L. → *Pinus* L. → *Populus* L. → *Tilia* L. → *Betula* L. → *Acer* L. → *Salix* L.

Therefore, *Aesculus* L. and *Pinus* L. species are not recommended for use in urban ecosystems plantations.

Middle resistant *Populus* L., *Tilia* L., *Betula* L., *Acer* L. species should be used in landscaping of recreation urban areas – parks, where the degree of anthropogenic pressure is not critical.

Resistant to pollution *Salix* L. species can be used as effective phytomeliorative plants around industrial areas and highways.

In scientific literature there is evidence of phytomeliorative prosperity of less common tree species in terms of urban environment, including forest beech (Gnativ, 2003b), oak (Michalak, 2011; Tulik, 2014), blue spruce (Kurnytska, 2001) and ash. However, this research is fragmental and need to be renewed.

Based on a critical analysis of literature it can be stated that the assessment of the vitality of trees in urboecosystem is an important fundamental and applied problem of bioecology because it allows one to develop scientific approaches to phytomelioration and bioindication of cities.

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