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ANALYSIS OF THE DENDROFLORISTIC COMPOSITION OF URBAN STREET TREE PLANTINGS IN SOFIA

Svetlana ANISIMOVA

University of Forestry, 10 Kliment Okhridsky Blvd, 1797, Sofia, Bulgaria

Corresponding author email: sanisimova@ltu.bg

Abstract

Street landscaping is that part of the urban green infrastructure that is crucial for urban heat island mitigation, climate change adaptation and biodiversity protection. Moreover, it provides city dwellers with various ecosystem services and daily accessible public greenspace. The aim of this research is to assess the street tree diversity of the city of Sofia. A total of 10,011 street tree specimens were inventoried. The field studies were conducted from 2021 to 2022, according to the route method. The selection of the sample streets for the survey was made based on the following criteria: street tree plantings covered all street classes of the primary and secondary street network and the variety of possible orientations and street canyon geometries; street tree plantings were located in different administrative territorial units of Sofia Municipality and the survey covered the entire length of the streets. In order to make an approximate assessment of the age of the specimens along the surveyed streets, DBH of each street tree stem was also collected and classified into categories. The established species composition in the surveyed streets consists of 55 taxa (species and cultivars). The most commonly used tree species in the new street plantings of the whole city street network was Platanus x *acerifolia (15.09%), while the most prevalent genera was Fraxinus (19.58%). One of the important findings in the analysis of the dendrofloristic composition was the low species diversity at street level. In most of the streets the number of species participating with more than 10% is 2-3. The analysis of the ratio of native to non-native (incl. cultivated varieties) street tree species showed that the non-native species and infraspecific taxa accounted for 57.32% of the total number of specimens. The results of the study can provide general guidelines for sustainable street plantings planning and design incl. selection of dendrofloristic composition for diverse street tree populations.*

Key words: *biodiversity, street trees, landscape design.*

INTRODUCTION

Street landscaping is that part of the urban green infrastructure that is crucial for urban heat island mitigation, climate change adaptation and biodiversity protection. Moreover, it provides city dwellers with various ecosystem services and daily accessible public greenspace near their home and workplace (Salmond et al., 2016; Ekkel & de Vries, 2017; Endreny, 2018; Marselle et al., 2020).

Urban streets are an inhospitable environment for tree growth (Paganová and Jureková, 2012). Some of the abiotic and biotic stress factors associated with street planting locations include anthropogenic compacted soils, inadequate soil volume and quality, impervious surfaces, overheating of the root zone, water deficiency, soil salinity caused by the accumulation of road de-icing salts, artificial lighting, air and soil pollution, urban heat island and street canyon effect, improper pruning, mechanical damage, etc. These harsh conditions not only negatively impact tree growth and mortality, but also reduce the list of appropriate street tree species and genera (Cowett & Bassuk, 2017).

The design approach adopted in Europe in the sixteenth century (Couch, 1992) to achieve a uniform silhouette and foliage texture along street, avenue, boulevard profiles has led to many even-aged monoculture street plantations. However, the desired visual uniformity in street tree planting may be accomplished by using diverse taxa which exhibit sufficient similarities according to citizens' perceptions (Vogt et al., 2017).

Historically, the uniform single-species formal planting scheme has been appreciated both from the design point of view and in terms of simplified management (Roman & Eisenman, 2022). However, the dendrofloristic and genetic diversity of tree populations has been associated with enhanced resilience to climate change (Lohr et al., 2016) and pests and pathogens (Laçan & McBride, 2008). The monocultures in urban green infrastructure pose a risk of large-scale pest and disease outbreaks (Santamour, 1990). In this context, street tree diversity assessment has been considered part of sustainable urban tree population management (Raupp et al., 2006; Sjöman & Östberg, 2019).

Santamour (1990) suggested the so-called 10-20-30 rule for ensuring diversity within a municipality's street tree population. The author proposed that no tree community should comprise: (1) more than 10% of any particular tree species; (2) more than 20% of any one tree genus, and more than 30% of any single family. Moreover, Santamour emphasized the importance of even distributions of street tree taxa (families, genera, species, cultivated varieties, clones) in urban street tree populations in order to achieve diversity at spatial and biological levels.

Some forest researchers dismissed Santamour's rule, because there is little empirical evidence to support these reference indices (Kendal et al., 2014) and proposed stricter rules for managing diversity. Bassuk et al. (2009) recommended that any street tree species should be limited to between 5% and 10% of the whole street tree population, while Ball (2015) suggested that any street tree genus should be limited to 5% of the street tree population.

Another important public health aspect related to increased species biodiversity and distribution evenness in urban green infrastructure is the avoidance of exposure to large, concentrated sources of monospecific allergenic pollen, one of the ecosystem disservices associated with urban street trees (Cariñanos & Casares-Porcel, 2011).

Additionally, these linear elements of green infrastructure, providing interconnection between green spaces, have been of a great importance to urban wildlife, and to avifauna in particular (Lepczyk et al., 2017). The value of indigenous species and selected exotic woody species utilized in street trees plantings as habitats and food resources for birds is high (Narango et al., 2017; Wood & Esaian, 2020).

The history of street tree plantings in the city of Sofia started after the Liberation. After 1879, with urban development, the first avenue trees were planted along the new city streets and boulevards. The intensive development of street landscaping began in 1880-1883, after the adoption of the first Master plan of Sofia. The main species in the streetscape in that period were *Robinia pseudoacacia* L. and *Aesculus hippocastanum* L. By the end of 1941, for a 60-year period, more than 30,000 street tree specimens from the following taxa were planted: *Robinia pseudoacacia* 'Umbraculifera', *Acer* spp., *Platanus* spp., *Betula pendula* Roth, *Fraxinus* spp., *Populus* spp. among others. Later, in the period 1945-1965, *Quercus rubra* L. and *Tilia* spp. specimens were used along some boulevards (Kuleliev, 1994).

A more recent study (Delkov & Gateva, 2004) of the dendrological structure of Sofia street plantings determined *Fraxinus* spp. (27.9%), *Aesculus hyppocastanum* L. (15.5%), *Populus* spp. (13.5%), *Robinia pseudoacacia* L. (9.2%), *Acer* spp. (8.9%), *Tilia* spp. (8.9%), *Betula pendula* Roth. (7.6%), and *Quercus rubra* L. (1.4%) as the most widespread taxa.

Currently, Sofia Municipality is developing an interactive map and register of green areas and mapped vegetation (https://ropkr.sofia.bg/) for the trees in its green infrastructure, incl. those lining streets, but it has not been completed yet.

The aim of this research is to assess the street tree diversity of the city of Sofia.

Collecting a street tree inventory data is essential for the management of this urban green infrastructure element. A total inventory (census) and mapping of the street trees specimens provide comprehensive data on the dendrofloristic composition, spatial distribution, prevailing DBH/ age classes, health status and maintenance issues. Moreover, sampling of street tree populations also provides efficient general information on street tree population characteristics (Smiley & Baker, 1988; Nowak et al., 2015).

MATERIALS AND METHODS

The street tree diversity has been assessed based on the data collected from sample street tree on-site inventory of Sofia street tree populations.

The field studies to establish the dendrofloristic composition were conducted from 2021 to 2022, according to the route method. The selection of the sample streets for the survey was made based on the following criteria: street tree plantings should cover all street classes of the primary and secondary street network and the variety of possible orientations and street canyon geometries; street tree plantings should be located in different administrative territorial units of Sofia Municipality and the survey should cover the entire length of the streets.

In order to make an approximate assessment of the age of the specimens along the surveyed streets, the dendrometric indicator - diameter at breast height (DBH) of each street tree stem was also collected and classified into categories.

The metrics employed to assess street tree diversity were: frequency distribution and Simpson's Diversity Index**.**

The relative abundance/distribution evenness of street tree taxa (species and genera) were calculated as a percentage at different levels (single street tree population, street tree population of different street classes, street tree population of the whole city).

Simpson's Index of Diversity (Simpson, 1949) considers the population size and species richness (the number of species in the population). The Inverse Diversity Index (1/D) was adopted for measuring species diversity. A higher value (near to 1) represents greater diversity, and a lower value (close to 0) indicates lower diversity.

An analysis of the ratio of native to non-native tree species (incl. cultivated varieties) and of a prevailing indigenous species was performed.

RESULTS AND DISCUSSIONS

General characteristics of Sofia street network

The street tree diversity of street tree popular-tions along 46 streets in Sofia was assessed, both within the Central city part and in the territory outside it (Figure 1). A total of 10,011 specimens were inventoried, 3,258 - along II class streets, 3,895 - along III class streets, 1,269 - along IV class streets and 1,589 - along V class streets.

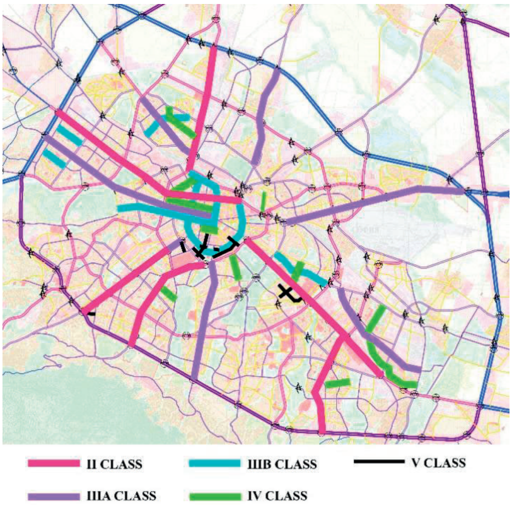

Figure 1. Surveyed streets in the Sofia street network

The focus of the research was the streets of the primary street network (II, III, IV class streets). The survey covered 6 II class streets, 8 III-A class streets, 10 III-B class streets, 9 IV class streets. They are the main communication and transport system of the urbanized territories and connect the different administrative territorial units of Sofia Municipality with each other, as well as with the republican and municipal road network. In connection with their function, these are streets with heavy vehicular and pedestrian traffic and with unfavorable conditions for the development of woody vegetation compared to the streets of the secondary street network.

The streets of the secondary street network lead and distribute the traffic from the primary street network to the urbanized units and serve individual properties. A total of 13 V class streets were surveyed.

The surveyed trees were mainly ones planted in sidewalk cutouts and rarely in road median strips or curb strips along all street classes.

Dendrofloristic composition of Sofia street plantings

The results from the inventory of the dendroflo-ristic composition of urban street tree plantings in Sofia showed that the total number of taxa was 55 in terms of species and infraspecific taxa (cultivated varieties), belonging to 19 families and 30 genera. This list includes a lot of single specimens of a taxa, while the diversity along streets in most cases was dominated by 18 taxa (Figure 2). The ones with a relative abundance greater than 5% were *Populus* x *euroamericana* (5.59%), *Fraxinus angustifolia* Vahl. (5.70%), *Tilia tomentosa* Moench. (5.85%), *Quercus rubra* L. (6.31%), *Fraxinus excelsior* L. (incl. 'Globosa') (8.36%), *Aesculus hippocastanum* L. (9.73%). The taxa with a relative abundance greater than 10%, which exceeded Santamour's 10% rule for species, were *Acer platanoides* L. (incl. 'Globosum', 'Crimson King'/'Royal Red') (11.74%) and *Platanus* x *acerifolia* (Aiton) Willd. (15.09%).

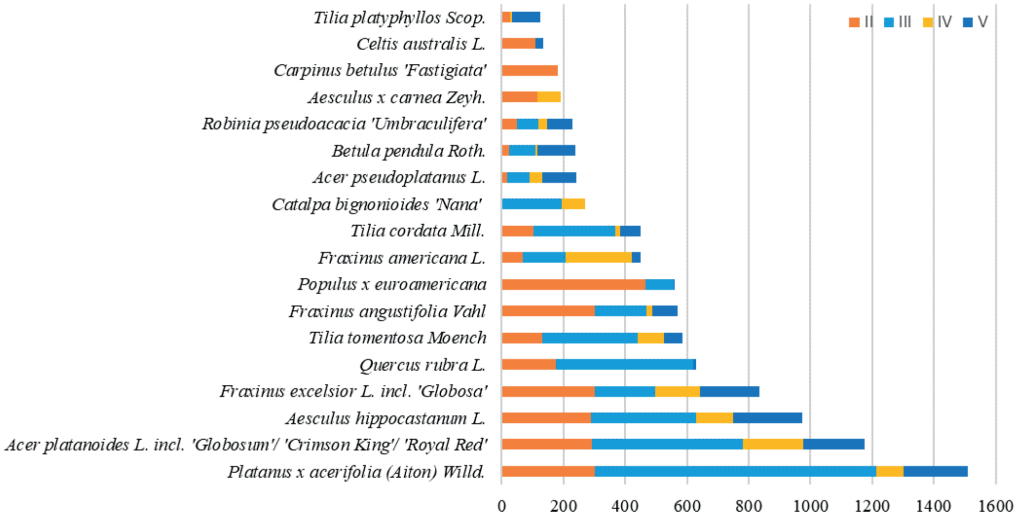

Figure 2. Relative abundance of street tree species in Sofia

These results support the worldwide tendency of *P.* x *acerifolia* to dominate as a street tree.

The European pilot tree survey has shown that species from the genera *Platanus* L., *Aesculus* L., *Acer* L., *Tilia* L. comprise 50-70% of all street trees planted (Pauleit, 2003).

Platanus x *acerifolia* was the most abundant street tree species in Amsterdam, Bologna, Buenos Aires, Melbourne, and Paris, while *Acer* spp. were the most dominant species in the streets of Cambridge, Oslo, and Vancouver (Galle et al., 2021).

The common species for street tree plantings in Bucharest were *F. excelsior, P.* x *acerifolia, A. hippocastanum*, *Tilia* spp., among others. Moreover, *P.* x *acerifolia* was found to be a dominant species (up to 88%) for some alignments (Dobrescu & Fabian, 2017). A recent survey of two New Belgrade boulevards showed that *P.* x *acerifolia* specimens accounted for 30.14% and 79.13%, respectively, which makes it the prevailing taxa among street trees (Milutinović et al., 2022).

In recent years the number of *Platanus* trees in the city of Poznan has shown a noticeable increase with a total number of over 1,500 specimens (Nowak et al., 2012). This species prevails in street tree plantings in northeastern US cities (Roman & Eisenman, 2022).

Platanus x *acerifolia* demonstrates high Environmental Stress Tolerance (EST) in terms of resilience to water stress and toxic ambient urban pollutants (Tiwary et al., 2016). On the other hand, *Platanus* spp. have been proved to be one of the main urban emitters of allergenic pollen (Cariñanos et al., 2020; Magyar et al.,

2022) and Biogenic Volatile Organic Compounds (BVOCs) (Xiaoshan et al., 2000; Curtis et al., 2014; Jing et al., 2020).

In relation to the aforementioned disservices, its further planting in public urban green areas should be restricted. Moreover, Georgieva et al. (2023), assessing the health status of this species in urban green areas of Sofia, noted the impact of biotic factors, pests and fungal pathogen infections on the performance of *Platanus* specimens. The authors warned about the potential threat posed by the pathogen *Ceratocystis platani* that had a destructive effect on the green infrastructure of the neighboring Greece and Turkey, causing the widespread mortality of plane trees.

The most common indigenous species in the streetscape of Sofia was *A. hippocastanum*, which is considered to be a symbol of the city of Sofia. However, the specimens cultivated as urban street trees had not only reduced vitality and longevity, but also low ornamental performance. Moreover, the health status of 22% of the investigated specimens made them potentially hazardous for city dwellers. (Pencheva & Anisimova, 2016).

The inventory data on street tree species composition revealed that the species that exceeded Santamour's 10% rule were: for II street class - *P.* x *euroamericana* (14.33%), while *F. angustifolia* (9.24%) and *P.* x *acerifolia* (9.24%) were close to the benchmark; for III street class - *P.* x *acerifolia* (23.42%) and *Q. rubra* (11.43%); for IV street class – *F. americana* L. (15.78%) and *A. platanoides* 'Globosum' (10.96%); for V street class - *A. hippocastanum* (14.02%), *P.* x *acerifolia* (13.07%), *A. platanoides* 'Globosum' (11.19%).

The inventory data on street tree genus composition revealed that the genera that exceeded Santamour's 20% benchmark were: for II street class *Fraxinus* (21.03%), for III street class - *Platanus* (23.52%); for IV street class - *Fraxinus* (33.68%), *Acer* (19.48%) was close to the benchmark; for V street class - *Fraxinus* (21.68%), *Acer* (19.92%) was close to the benchmark.

The Inverse Simpson's Diversity Index (1/SDI) was calculated for the whole street population as an index that takes into account both species richness and the evenness of the species present. The high species diversity of Sofia street trees (0.94) was attributed mainly to the greater number of less abundant species rather than to their more even distributions. However, it was found that just 2.49 ± 0.99 number species with relative abundance greater than 10% comprise 84.46 ± 13.14% of the total street tree population at street level.

Among all street tree genera, *Fraxinus* was found to be the most prevalent in the whole city street network (19.58%), followed by *Platanus* (15.34%), *Acer* (14.38%), *Aesculus* (11.70%), *Tilia* (11.60%) (Figure 3). These five genera comprised 72.62% of the total street tree population. *Fraxinus*' relative abundance was close to Santamour's benchmark at genus level - 20%.

In comparison, *Tilia* was found to be the most common genus (21.09%) of the whole tree population in ten major Nordic cities, followed by *Acer* (12.34%), *Sorbus* (10.41%) and *Betula* (10.22%) (Sjöman & Östberg, 2019).

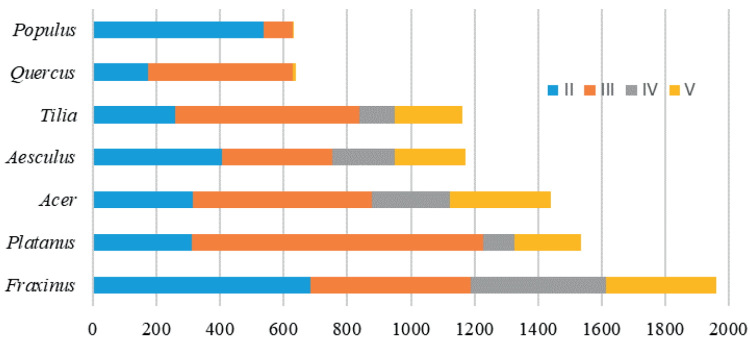

Figure 3. Relative abundance of the most common genera in Sofia street tree plantings

The analysis of family composition revealed that none of the families surpassed Santamour's 30% rule for family level - Sapindaceae (26.09%), Oleaceae (19.58%), Platanceae (15.34%), Malvaceae (11.6%).

The age structure of the street tree population of the surveyed streets was assessed using the dendrometric indicator - diameter at breast height (DBH) (Figure 4).

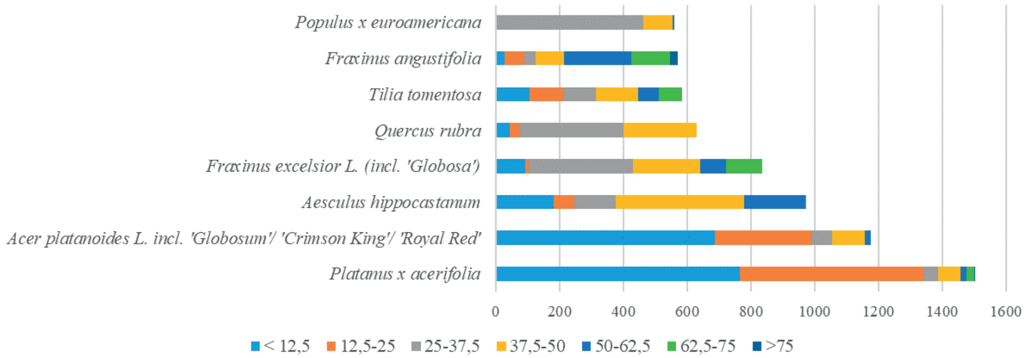

Figure 4. Structure by categories of diameter classes for the main species

The results show that about 1/2 of the specimens were up to 25 cm in diameter, and nearly 15% were over 50 cm in diameter, which is an indicator of aging and a cause for urgent measures for their phased replacement. The analysis of DBH indicated the dominant presence of young *P.* x *acerifolia* and *Acer platanoides* 'Globosum' specimens (DBH < 25).

The key to increasing diversity and making a significant structural change in municipal street tree dendrofloristic composition, respectively, is a long-term strategy of replacing more dominant species and genera that have reached senior stage with less prevalent and appropriate species and genera. Thus, the transition to greater diversity may be accomplished more quickly for municipalities where the street tree population is in decline than in municipalities with younger street tree plantings (Cowett & Bassuk, 2017). Biodiversification at different taxonomic ranks could be achieved by planting underutilized native tree species (Hilbert et al., 2022).

As part of the dendrofloristic characteristics, the analysis of the ratio of native to non-native (incl. cultivated varieties) street tree species showed that the non-native species and infraspecific taxa accounted for 57.32% of the total number of specimens (Figure 5).

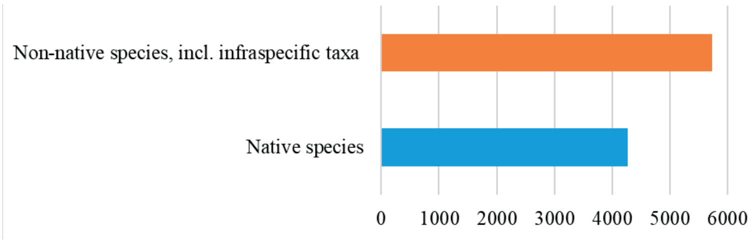

Figure 5. Relative abundance of native and non-native species, incl. infraspecific taxa

A concerning trend towards the large scale use of exotic species and cultivars in the green infrastructure was reported in many studies (Pysek et al., 2009; Morgenroth et al., 2016; Anisimova, 2018; Useni Sikuzani et al., 2022).

CONCLUSIONS

The results indicate a relatively low species diversity in the current city street populations at street level. The most commonly used tree species in the new street plantings of the whole city street network was *Platanus* x *acerifolia,* while the most prevalent genera was *Fraxinus*.

A database should be developed with a complete street tree inventory, which has to be updated regularly in order to contain comprehensive data on streetscape species composition, age structure and spatial distribution, health status, establishment of young trees, essential information for street tree planning and management. Long-term observations could track and evaluate changes in the street tree population in the context of climate change.

Official guidelines/standards on the management and maintenance of street tree plantings, incl. monitoring, should be developed and adopted by Sofia Municipality.

The concept of sustainable development of urban green infrastructure should include not only the spatial distribution of street plantings, but should also define the street tree selection criterion and species composition in order to ensure adequate street tree diversity at different levels (at street level, administrative territorial level and city level).

The results from such inventories should be taken into consideration by local nurseries in order to organize production/import and to provide the municipality with semi-mature, properly trained, standard street trees from diverse and less prevalent species and genera.

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