Scientific Papers. Series B, Horticulture. Vol. LXVIII, No. 2, 2024
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

A GIS APPROACH TO GREEN REGISTER AND TREE MANAGEMENT IN BUCHAREST, ROMANIA - DISTRICT 1 CASE STUDY

Anca-Roxana STRUGARIU[1], Marius BUDILEANU[2]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Mărăşti Blvd, District 1, Bucharest, Romania
[2]University of Bucharest, Faculty of Geography, 1 Nicolae Bălcescu Blvd, District 1, Bucharest, Romania

Corresponding author email: anca.roxana.strugariu@gmail.com

Abstract

This paper aims to analyse the concept of a green register, the component elements of a register, its utility and necessity, especially in the urban environment, using geospatial techniques and Geographic Information Systems (GIS). In the introduction phase, the international, national, and local situations were studied to determine the importance of trees and green areas. For the results and discussion phase, the trees located in the "Regina Maria" Park were identified, while the statistical data were centralised to establish the vegetation structure (species and their distribution, invasive potential, other characteristics). Last, but not least, recommendations were made to support the long-term maintenance of these trees. Thus, the phytosanitary issues were centralised to prevent human and material damage, while a management plan was drawn up with specific interventions and action points.

***Key words**: green register, green infrastructure, tree assessment and management, Bucharest, Geographic Information Systems.*

INTRODUCTION

A green register functions as a document outlining strategies and policy guidelines for the management and maintenance of vegetation in a study area or a city. It can provide valuable information on conservation, potential planting activities, tree removal, and maintenance work. Green spaces produce numerous benefits for people, especially in urban environments affected by pollution, real estate developments, and more. In the current context of climate change, ensuring a landscape management plan becomes a priority.

Monitoring green spaces, and implicitly, the trees, is essential for determining the index of green space per inhabitant, improving the urban microclimate, developing green-blue strategies, maintaining and developing green spaces. The optimization of territorial arrangements with ecological, aesthetic, and recreational purposes is also crucial.

At the international level, various institutions and organizations have initiated actions and activities aimed at drawing attention to the need to protect nature and encouraging the development of strategies and projects to improve the quality of urban life. National and local standards regarding the adequate area of public space differ significantly from one country to another.

For instance, the World Health Organization recommends a minimum surface of 9 m^2 of open green space per person (WHO, 2009).

Although there are inconsistencies regarding how green space is defined and perceived, many cities are striving to achieve this minimum recommendation, while others aspire to a much more generous green surface, such as the Italian law that mandates 18 m^2 of green area per person in new urban developments (EAA, Urban Agenda for the EU, 2022).

On average, around 40% of the area of European cities is comprised of urban green infrastructure, with approximately 18.2 m^2 of publicly accessible green space per inhabitant, while 44% of Europe's urban population lives within 300 m of a public park (Maes et al., 2018; Corbane et al., 2020).

However, the presence of green areas, both public and private, in cities varies greatly. While some city centers, such as Vienna (Austria) and Freiburg (Germany), even have forested areas in their midst, others lack any green spaces (Maes et al., 2018; Corbane et al., 2020). This disparity is particularly noticeable in Mediterranean regions, as illustrated in Figure 1.

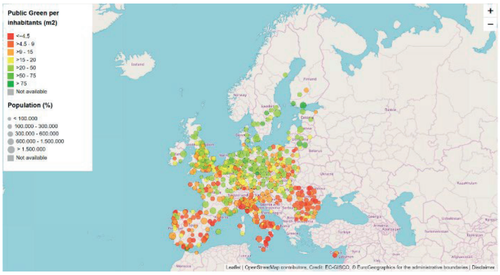

Figure 1. Public green space available per inhabitant in European cities. Source: CE JRC, Maes et al., 2019

The importance of trees in the urban environment is also recognized in the European Union Biodiversity Strategy for 2030, which mandates that cities with more than 20,000 inhabitants develop urban greening plans. These plans should encompass measures to create diverse and accessible urban green spaces, including parks, forests, and street alignments.

At the national level, specific regulations regarding green spaces and intervention on trees have been established through laws and emergency ordinances, as well as local council decisions.

Green spaces are defined by Law no. 24/2007 on the regulation and administration of green spaces in urban areas, with subsequent amendments and additions.

According to O.U.G no. 114/2007 for the amendment and completion of the Government Emergency Ordinance no. 195/2005 on environmental protection, Art. II, para. (1), local public administration authorities are obligated to ensure a green space area of at least 20 m^2/inhabitant until December 31, 2010, and at least 26 m^2/inhabitant until December 31, 2013.

In this sense, the local public administration has the obligation to keep track of green spaces within the territorial administrative unit by creating the register of green spaces.

The Greenpeace Romania organization analysed the establishment of the green register at the level of the Municipality of Bucharest and affirms the fact that in 1989 each inhabitant of Bucharest had at their disposal, on average, an area of 16.79 m^2 of green spaces.

In 2006, a report by the Bucharest City Hall showed that the area of green space per inhabitant was reduced to 9.67 m^2. At the end of 2011, the public administration completed the Register of Green Spaces.

According to Greenpeace Romania, the measurements of the Bucharest City Hall revealed in 2011, 23.21 m^2 per inhabitant, more than double the figures previously presented. Comparatively, Vienna had, in 2012, an area of 120 m^2 of green space per inhabitant, followed by Helsinki (100) and Stockholm (86). Capitals much larger than Bucharest had more green space, among them London - 27 m^2, Berlin - 38 m^2 and Rome - 45 m^2 (Greenpeace, 2020).

The Court of Accounts showed, however, that this massive increase in 2011 in the area of green spaces per inhabitant was done superficially. The data used also contain the surfaces of the green space related to the private domain. According to the Court of Accounts, in 2014 Bucharest had only 9.86 m^2 of green space per inhabitant, not 23.21, as announced by the authorities (Greenpeace, 2020).

Although by 2013, the area of green space per inhabitant was supposed to reach 26 m^2, according to the national legislation in force and the rules of the European Union, this ideal is still unfulfilled. From 2011 until now, despite the publication of the Green Register in 2013, no updates of its data have been made.

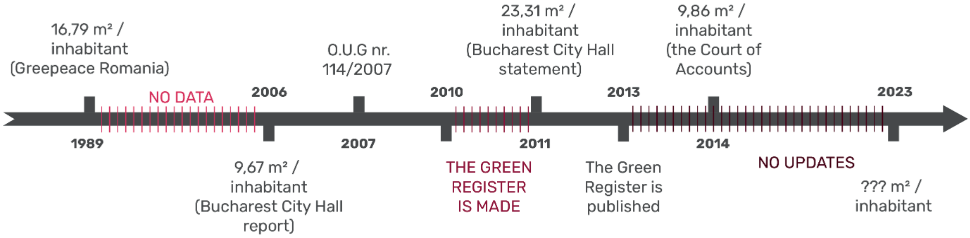

Figure 2. Illustrative scheme regarding the Green Register's situation in Bucharest

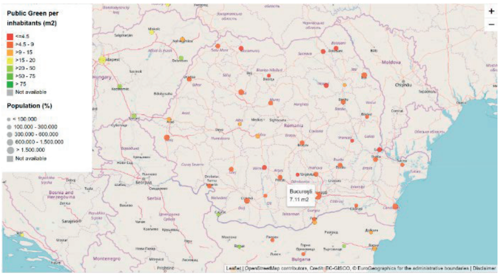

Figure 3. Public green space available/inhabitant in Bucharest (7.11 m^2) (Source: CE JRC, Maes et al., 2019)

In 2022, a research report on the state of the environment in Bucharest was published based on the Green Register made in 2011, detailing the components of the city's green infrastructure, as shown in Figure 4.
The report notes that the distribution of the existing green space is insufficient and uneven. According to the report, the largest area of green space is available in District 1, which will be analysed during this study, representing 77 m^2 of green space and 2.44 trees for each inhabitant. At the opposite pole is District 2, with the least green space and the fewest trees (Buletin de Bucureşti, 2022).

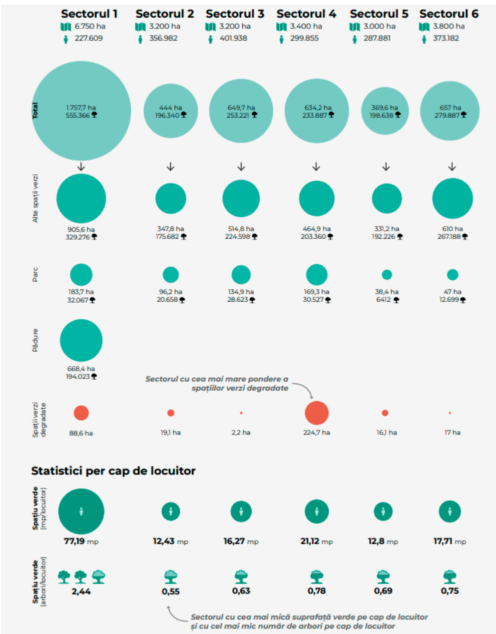

Figure 4. The green spaces related to each district (Source: Raport de cercetare privind starea mediului în Bucureşti, 2022)

MATERIALS AND METHODS

To begin with, a macro-level processing was carried out for the entire District 1, using satellite images, to determine the normalized difference vegetation index (NDVI) and the land surface temperature (LST). This processing was prepared as a complement to the situation presented in the introduction, in order to observe the degree of vegetation cover and the way in which parks and tree vegetation contribute to lowering temperatures.
For this stage, Landsat 8 images were used, taken from the www.earthexplorer.usgs.gov platform, from two different moments, 10.06.2013 and 06.06.2023, also representing a comparative analysis.
At the micro-level, “Regina Maria” Park was chosen in order to create a green register. Opting for a park over an alignment or a boulevard enhances ecological diversity.
The process involved identifying and inventorying the trees of the studied site, while their placement was carried out using the QField application.

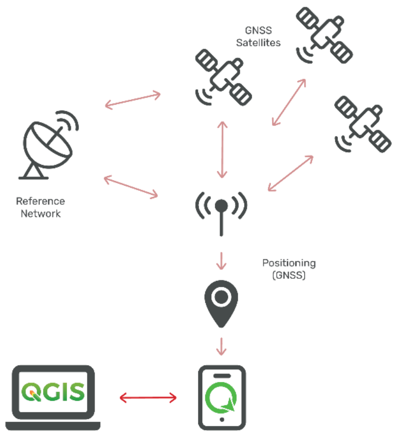

Figure 5. Workflow for synchronizing data collected in the field through QField for QGIS

Taxonomic data and phytosanitary status characteristic of each specimen were recorded. This data includes: species and variety (where applicable), health status (excellent, good, reasonable, deficient, dry/dead, stump), age category (young, mature, declining specimens), biological origin of the species (native or non-native), and invasive potential.

The purpose of this information is to understand the existing tree composition and identify any problems or risks. The collected data can act as an archive for each tree, helping ensure compliance with legal requirements and serving as a reference for monitoring and implementing specific commands in the field.
For this study, both vector and raster geospatial data were utilised to create the thematic maps, graphics, and their interpretation.

Table 1. Types and sources of data used

Type of data extracted	Data sources
Vector data: built space, street network, UAT limits, county limits, park limits, cemeteries limits, forest limits, hydrography	https://geoportal.ancpi.ro/portal/home/ www.openstreetmap.org
Satellite images: Landsat 8, Sentinel-2, Google Maps / Google Earth	www.earthexplorer.usgs.gov https://scihub.copernicus.eu/ Google Earth Pro, Google Satellite
Topographic map “Regina Maria” Park (1978, 2022)	Administrația Domeniului Public Sector 1
Data on green spaces	Primăria Municipiului București - https://www2.pmb.ro/ Administrația Domeniului Public Sector 1 - https://adp-sector1.ro/
Software for field data extraction	QField
Data processing software	ArcMap, QGIS
Map styling software	Adobe Illustrator, Adobe Photoshop, Autodesk AutoCAD
Software for creating graphics	Microsoft Excel

RESULTS AND DISCUSSIONS

The first step for the results and discussions phase was to centralise the green and blue infrastructure of the District 1.
According to the Law no. 24/2007, Art. IV, a), for the purposes of this law, the term “park” has the following meaning: a park is defined as a green space with an area of at least one hectare, consisting of a specific plant framework and built-up areas, including facilities and equipment intended for cultural-educational, sports, or recreational activities for the population.

Table 2. Green infrastructure - parks of District 1

GREEN INFRASTRUCTURE - PARKS OF DISTRICT 1		
Name	Surface	Administrator
“Regele Mihai I al României” Park (Herăstrău)	141.8 ha	Bucharest City Hall (PMB)
Cișmigiu Park	15.7 ha	PMB
Kiseleff Park	14 ha	District 1
Bazilescu Park	13.1 ha	District 1
Bordei Park	8.4 ha	PMB
Floreasca Park	7.8 ha	PMB
Operei Park	4.7 ha	District 1
“Regina Maria” Park	1.6 ha	District 1
“Elisabeta Rizea” Park	1.5 ha	District 1
Gării de Nord Park	1.5 ha	District 1

Table 3. Blue infrastructure - lakes of District 1

BLUE INFRASTRUCTURE - LAKES OF DISTRICT 1		
Name	Surface	Administrator
Herăstrău Lake	77 ha	PMB
Grivița Lake	75.85 ha	PMB
Floreasca Lake	70 ha	PMB
Străulești Lake	44 ha	PMB
Băneasa Lake	40 ha	PMB
Cișmigiu Lake	2.65 ha	PMB

Despite the considerable green space areas of District 1 compared to the rest of the districts of the Municipality of Bucharest, their distribution is disproportionately skewed, as displayed in Figures 6 and 7.

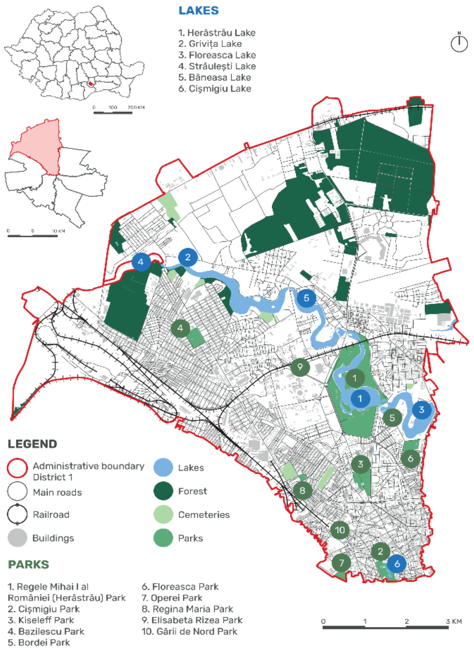

Figure 6. Blue-green infrastructure in District 1

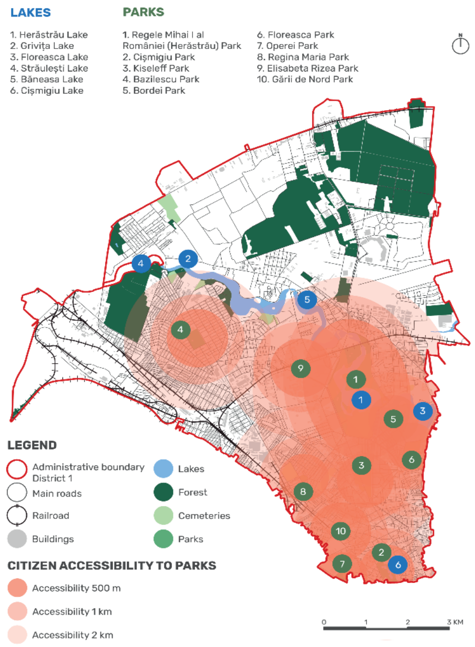

Figure 7. Citizen accessibility to parks (500 m, 1 km, 2 km)

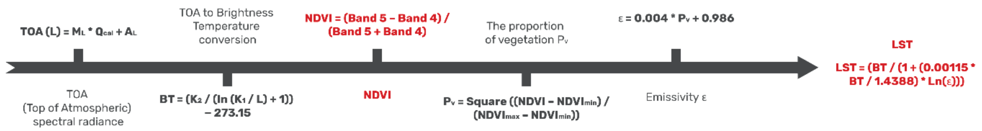

Figure 8. Workflow for processing NDVI and LST using ArcMap

Two analyses, NDVI (Normalized Difference Vegetation Index), and LST (Landscape Surface Temperature), were conducted for the month of June in 2013 and 2023, respectively, using the formulas shown in Figure 8 above.

NDVI, the Normalized Difference Vegetation Index, indicates the health of vegetation based on leaf chlorophyll content, reflecting the amount of plant biomass. NDVI values range from -1 to 1. Thus, the higher the NDVI, the healthier the vegetation (Agrivi App, 2022).

LST, land surface temperature, is an index that quantifies the thermal radiation emitted by the Earth's surface. It describes processes such as the exchange of energy and water between the land surface and the atmosphere, influencing the rate and timing of vegetation growth.

LST data helps understand and monitor heat patterns in urban areas, analyse land-atmosphere interactions, and study the thermal behaviour of different types of land cover.

It is found that, for the NDVI analysis (Figures 9 and 11), the differences in values are not significant over the two years analysed, except for the central area, where the situation improves in 2023 compared to 2013. However, this area is the most affected in terms of thermal stress.

The lowest NDVI values are around lakes, as water areas absorb both red and near-infrared light, resulting in negative NDVI values.

The highest values are distinguished in the parks and Băneasa Forest in the north of the district, as well as in the northwest corner, along the railway infrastructure, representing unbuilt land.

LST values are influenced by various factors, including solar radiation, cloud cover, vegetation cover, soil moisture, and local climatic conditions. It is important to note that LST represents the temperature of the land surface itself, which may differ from air temperatures measured at different heights in the atmosphere. For the two years analysed, a considerable improvement is noted in 2023 due to the development of the dendrological vegetation. The lowest temperatures are observed on the shores of the lakes, in the parks, in the Băneasa Forest area, as bodies of water and tree vegetation regulate the temperature and contribute to the reduction of thermal stress.

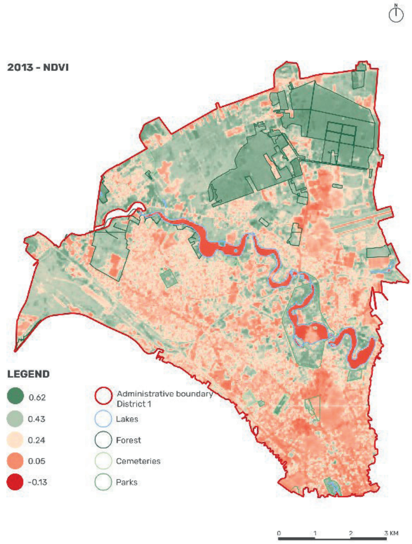

Figure 9. NDVI for 10.06.2013

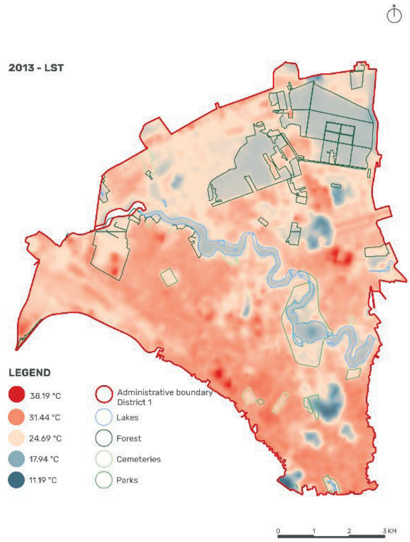

Figure 10. LST for 10.06.2013

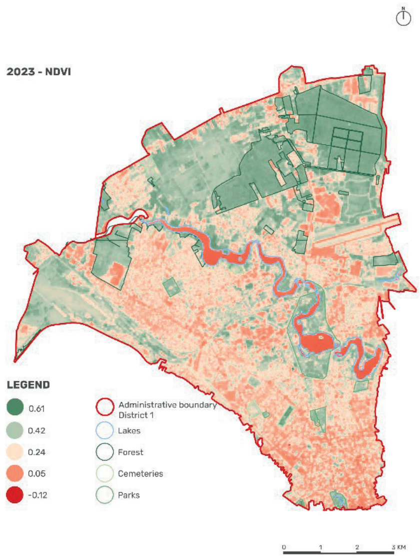

Figure 11. NDVI for 06.06.2023

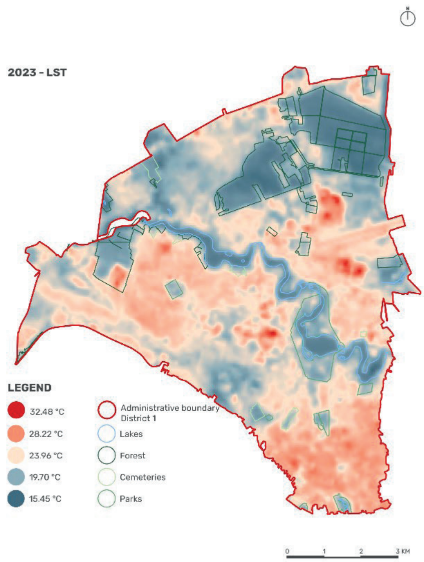

Figure 12. LST for 06.06.2023

Following the analyses of NDVI and LST, there was a desire to correlate the two indices, which are used on a large scale to study the relationship between vegetation dynamics and temperature patterns. A negative correlation may provide information about the chilling effect or the impact of drought stress on plant health. These indices find application in environmental monitoring, ecological studies, agricultural and biodiversity management, as well as climate change research.

The correlation was executed through the ArcMap program and involved creating a Fishnet (located in Arc Tool Box under Data Management Tool, Sampling, Create Fishnet) and extracting the values recorded for NDVI and LST (found in Spatial Analyst Tools, Extraction, Extract Multi Values to Point).

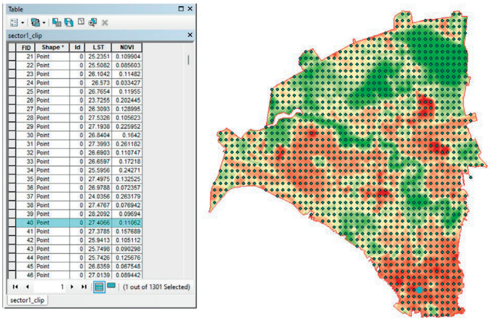

Figure 13. Screenshot from ArcMap illustrating correlated LST and NDVI values

In the attribute table, after removing the null values (Analysis Tools, Extract, Clip), the correlated values could be observed, and a graph could be created for illustrative representation, generated in Excel. It is noticed that the high values (+50-60) recorded for NDVI are situated in areas with lower temperatures, ranging between 20 and 25°C.

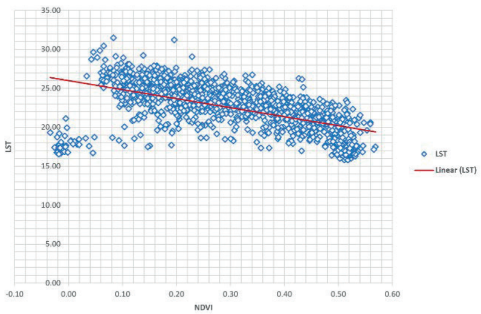

Figure 14. Illustrative graph regarding LST-NDVI correlation

For the micro-level analysis, the "Regina Maria" Park was examined, and a green register was established. The park is situated in the southwest area of District 1, near the border with District 6.

Figure 15. Map of the "Regina Maria" Park

In the "Regina Maria" Park, 410 tree specimens belonging to 29 species were identified and inventoried. Among these species, only two, *Acer negundo* and *Ailanthus altissima*, have invasive potential.

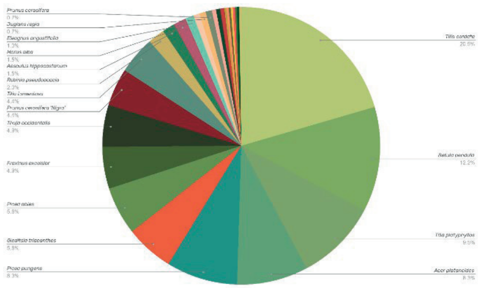

Figure 16. Illustrative graph for the registered trees

It is observed that the species representing more than 20% of the tree composition in the park is *Tilia cordata* (20.5%), followed by *Betula pendula* with 12.2% and *Tilia platyphyllos* with 9.5%. In between, there are *Acer platanoides* and *Picea pungens*, each accounting for 8.3%, and *Gleditsia triacanthos* and *Picea abies*, each with 5.6%. The least represented species include *Abies* spp., *Acer negundo*, *Ailanthus altissima*, *Catalpa bignonioides*, *Celtis occidentalis*, *Laburnum anagyroides*, *Malus domestica*, *Pinus sylvestris*, with only one specimen identified, representing 0.2% each.

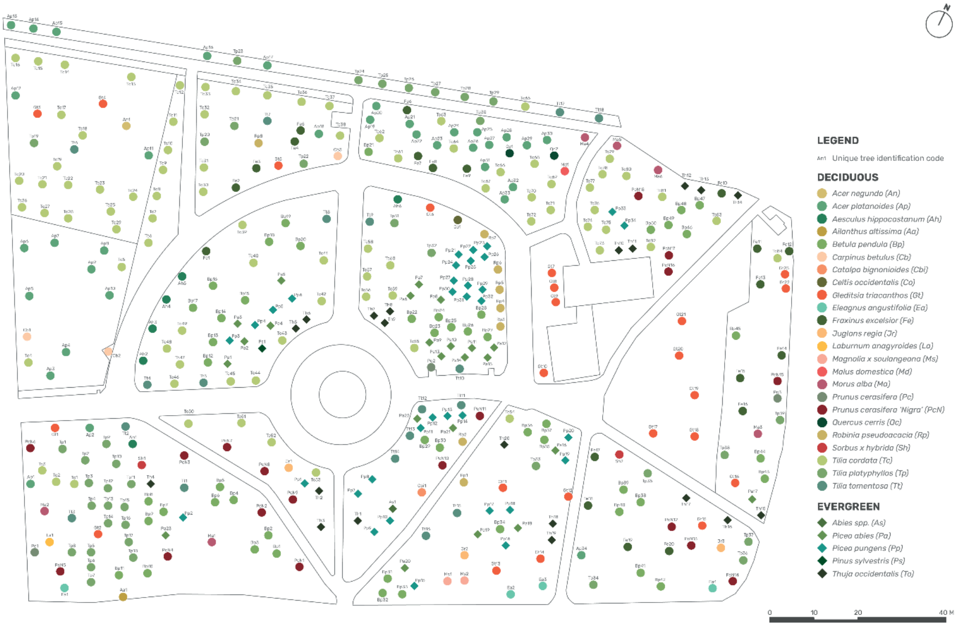

Figure 17. Map of identified and inventoried trees

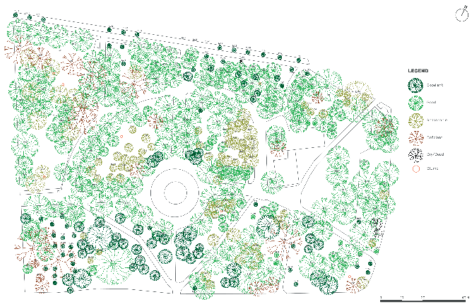

Figure 18. The phytosanitary status of the inventoried trees

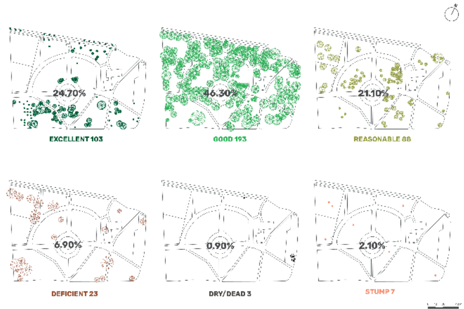

Figure 19. The phytosanitary status of the inventoried trees on categories

The data was also presented to illustrate the phytosanitary state, divided into six main categories (excellent, good, reasonable, deficient, dry/dead, stump).

Out of the 410 trees identified, 103 are in excellent condition, representing 24.70%, 193 are in good condition, accounting for the highest value of 46.30%. The reasonable is attributed to 88 trees, illustrating 21.10% of the composition, while the deficient state is observed in 23 trees, making up 6.90%. Additionally, 3 trees were identified as dry/dead, representing 0.90%. Furthermore, 7 stumps were observed, constituting 2.10% of the total 417 registrations.

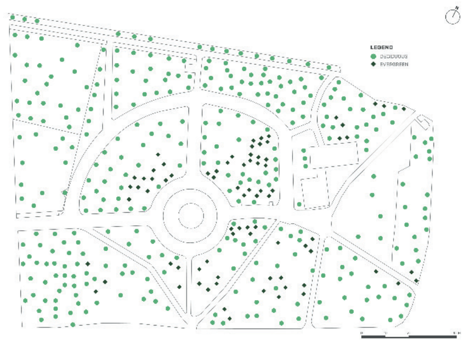

Figure 20. Distribution of deciduous specimens vs. evergreen

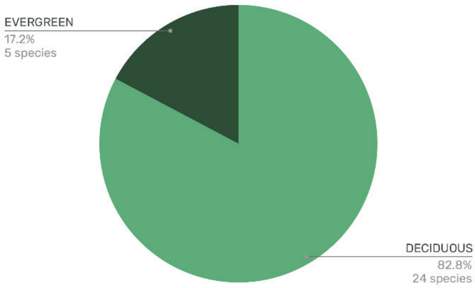

Figure 21. Distribution of the species

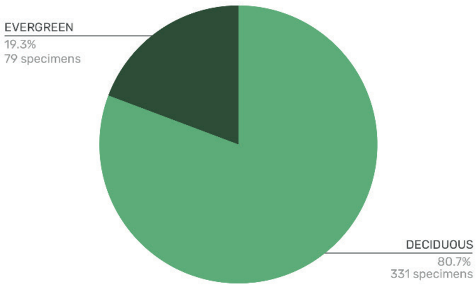

Figure 22. Distribution of the specimens

At the park level, 24 species of deciduous trees and 5 species of evergreen trees were identified. Regarding their distribution, there are a total of 331 deciduous specimens and 79 evergreen specimens.

Although the balance between native species (16) and non-native species (13) is approximately equal in terms of their presence in the park, native species predominate when considering the number of specimens. Specifically, 323 specimens of native species were recorded, while the total number of non-native specimens is 87.

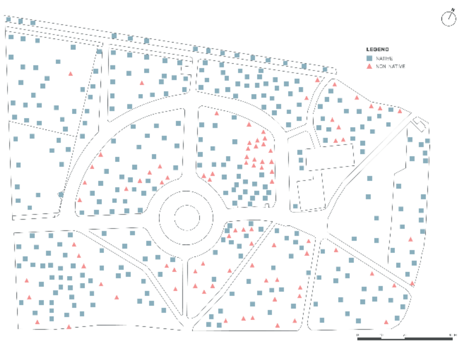
Figure 23. Distribution of native vs. non-native

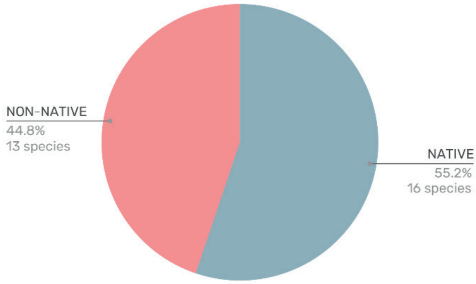

Figure 24. Distribution of the species

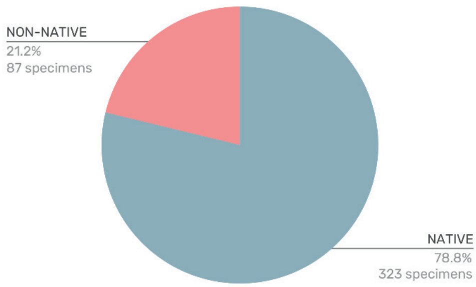

Figure 25. Distribution of the specimens

Concerning the age categories, 26 specimens in biological decline (experiencing at least one phytosanitary problem endangering the viability of the tree), 179 young specimens, and 205 mature specimens were recorded. While it is gratifying that numerous trees have been planted in the last 10 years (approximately the age of young specimens), not all of them were planted correctly, as some are situated beneath the already formed crown of mature specimens. This improper planting could impact the healthy growth and development of both the newly planted trees and the existing mature ones.

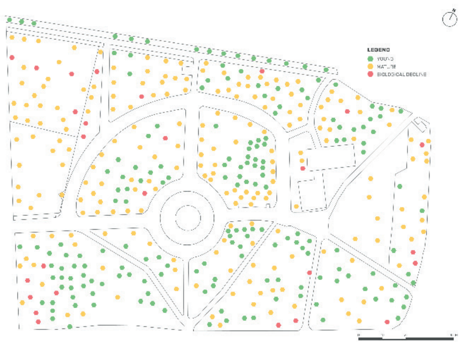
Figure 26. Distribution of age categories

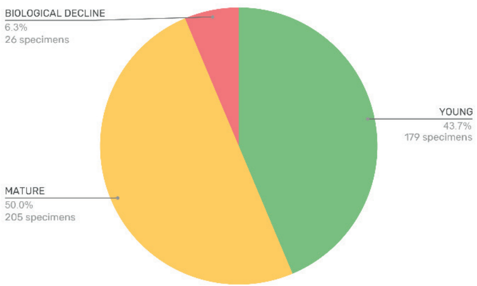

Figure 27. Illustrative graph for age categories

Among the phytosanitary issues, the following were identified on site: poor grip, broken, and dry branches, mechanical damage, rots on the parcel, trunk, and stems, damaged central cylinder, bent trunk, bacterial cancer, fungi saprophytes, and attack of caries or insects.

Figure 28. Phytosanitary issues identified on site

At the “Regina Maria” Park level, at least 7 out of the total of 29 identified species in the field exhibit bacterial cancer. Another common phytosanitary problem in the park is mechanical damage, resulting from improper pruning and trimming carried out in the past, affecting 9 out of the 29 species.

The primary causes of these symptoms include natural phenomena, such as wind, drought, and frost, pollution factors in air and soil, improperly executed maintenance works, such as cutting and trunk watering, transmission of pests from other planted specimens, and more.

Table 4. Phytosanitary issues identified for each species

Scientific name	Phytosanitary issues identified										
	poor grip branches	broken branches	dry branches	affected bark	mechanical damage	rots on the parcel/trunk/stems	damaged central cylinder	bent truck	attack by diseases and pests		
									bacterial cancer	fungi saprophytes	caries / insects
Abies spp.											
Acer negundo								■	■		■
Acer platanoides					■						
Aesculus hippocastanum			■		■				■		■
Ailanthus altissima											
Betula pendula			■					■	■		
Carpinus betulus					■						
Catalpa bignonioides					■						
Celtis occidentalis											
Gleditsia triacanthos									■	■	■
Eleagnus angustifolia	■	■	■	■		■		■			■
Fraxinus excelsior						■	■		■		
Juglans regia											
Laburnum anagyroides				■		■					■
Magnolia x soulangeana											
Malus domestica											
Morus alba				■	■	■	■		■		
Picea abies			■								
Picea pungens			■								
Pinus sylvestris									■		
Prunus cerasifera					■						■
Prunus cerasifera 'Nigra'			■	■		■					
Quercus cerris											
Robinia pseudoacacia					■						
Sorbus x hybrida											
Tilia cordata				■	■	■	■				■
Tilia platyphyllos											
Tilia tomentosa					■						
Thuja occidentalis			■								
Scientific name	poor grip branches	broken branches	dry branches	affected bark	mechanical damage	rots on the parcel/trunk/stems	damaged central cylinder	bent truck	bacterial cancer	fungi saprophytes	caries / insects
									attack by diseases and pests		
	Phytosanitary issues identified										

CONCLUSIONS

Dead/dry specimens (3) and those showing severe biological decline (7) are proposed for deforestation. For the remaining tree specimens that display phytosanitary problems or a deficient condition (16), it is suggested to use a tomographic device to accurately assess the viability of the tree and determine whether it represents an imminent danger. This comprehensive approach aims to ensure a through evaluation and appropriate action for trees with compromised conditions in the park.

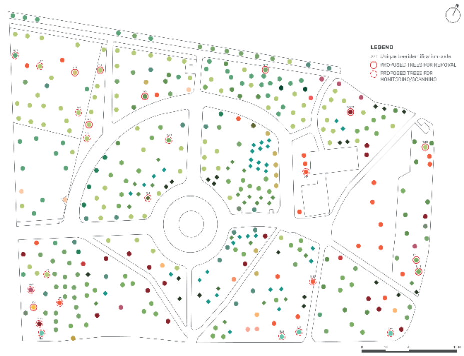

Figure 29. Proposed trees for removal and monitoring/scanning at the park level

The tomographic device can detect cavities and density differences present in the wood structure, as illustrated below in Figure 30.

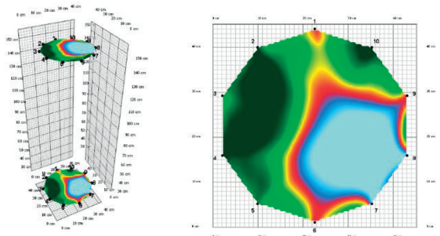

Figure 30. Example of using tree tomography (using ArborSonic 3D). Source: personal archive

Simultaneously, to comply with the provisions of Art. 7 of H.C.G.M.B 304/2009, it is assumed that for each viable deforested tree, six specimens from the same category of the decommissioned tree are planted as compensation. According to Art. 8 of the same decision, point 4) specifies the obligation to plant in compensation in a ratio of 1:1 for completely dry trees. Thus, at the park level, 7 stumps were identified that must be extracted and replaced according to the legal provisions with new dendrological material.
The implementation of a green register could facilitate monitoring compensatory tree planting, particularly in limited spaces that require prompt planting action.

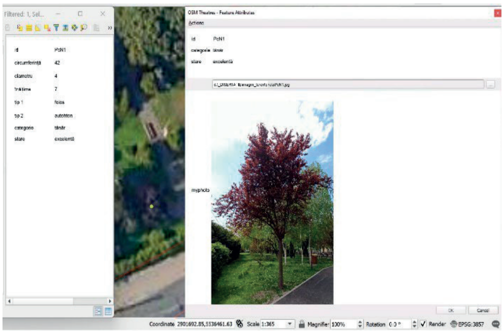

Figure 31. Screenshot from QGIS illustrating features via Open Attribute Table and publishing the image using Feature Attributes

To protect the trees from additional mechanical damage, a graphic was created for the pruning and trimming season for identified tree species. This could help making well-informed decisions on how to proceed.

Table 5. Pruning and trimming season for each species

Scientific name	Pruning and trimming trees											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Abies spp.												
Acer negundo	■	■						■				■
Acer platanoides	■	■						■				■
Aesculus hippocastanum	■										■	■
Ailanthus altissima		■	■									
Betula pendula	■											■
Carpinus betulus	■											■
Catalpa bignonioides	■	■									■	■
Celtis occidentalis	■	■										■
Gleditsia triacanthos	■	■										
Eleagnus angustifolia	■											■
Fraxinus excelsior	■	■						■				■
Juglans regia	■						■	■	■	■	■	■
Laburnum anagyroides							■					
Magnolia x soulangeana							■					
Malus domestica	■	■										■
Morus alba											■	■
Picea abies												
Picea pungens												
Pinus sylvestris												
Prunus cerasifera							■					
Prunus cerasifera 'Nigra'							■					
Quercus cerris	■	■	■									
Robinia pseudoacacia							■	■				
Sorbus x hybrida			■									
Tilia cordata	■						■	■	■	■	■	■
Tilia platyphyllos	■						■	■	■	■	■	■
Tilia tomentosa	■						■	■	■	■	■	■
Thuja occidentalis			■				■	■				

The heat island phenomenon raises the average annual temperatures in Bucharest by 0.9-1.2°C compared to the surrounding areas, with frequent instantaneous differences of 4-6°C higher. In the summer, the average annual temperature in Bucharest is 3-4°C higher than in the surroundings areas. The central area of the city is the most exposed to thermal stress (Raport de cercetare privind starea mediului în București, 2022). Therefore, ensuring proper tree management and planning any tree interventions according to a plan is mandatory.
Currently, Bucharest lacks a strategy and plan for adapting to climate change, a General Urban Plan, an Integrated Urban Development Strategy, or other instruments intended to support the fight against climate change, as well as the development of a green-blue strategy.
The primary purpose of a green register is to provide a database supporting decision-making, planning, and monitoring of environmental initiatives. A green register makes it easy to track progress towards sustainability goals.
A green register can also provide information on the degree of tree cover, resulting biomass level, the amount of carbon absorbed, and the quantity of trees and green space per inhabitant.

Geographic information systems play a significant role in landscape analysis, planning, and management. GIS allows the collection and analysis of various spatial data relevant to the landscape and beyond. By integrating and analysing datasets, geographic information systems can offer insights into landscape relationships and dynamics. GIS tools make it easier to identify sensitive areas and help minimize negative impacts by enabling informed decisions.

GIS assists in monitoring and mapping the distribution of plant species, identifying invasive species, and assessing vegetation health and condition. It can also be used to plan and implement habitat restoration or conservation projects by analysing suitable spaces and monitoring the effectiveness of interventions.

The implementation of a green register is crucial for the effective management of dendrological vegetation in the urban environment, establishing tree health, reducing risks, maximizing environmental benefits, as well as efficiently allocating resources.

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