

# Integrated assessment of urban green infrastructure condition in Karlovo urban area by *in-situ* observations and remote sensing

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## Abstract

The knowledge about urban green infrastructure (UGI) is important for maintaining the quality of life in cities, suburbs and the fringes of metropolitan areas. The perspective of rapid urban sprawl generates the need for establishment and use of adequate systems for monitoring the condition of the urban ecosystems and green spaces. This triggers the search for a stronger link between the condition of urban green infrastructure and its capacity to supply ecosystem services (ES). In this paper are presented the results of the assessment of the health status of tree and shrub vegetation in UGI of Karlovo through an integrated application of in-situ observation and remote sensing using Unmanned Aerial Vehicle (UAV) technology. The study showed that the implementation of this flexible approach provides rapid and low-cost results, with good quality of the generated information. This makes the approach appropriate as a basis for monitoring of green systems in urbanised areas, with subsequent detailed investigation of solitary trees for cataclysms and epiphytotics of native species and rapid detection for the population of invasive insect and pathogen's in order to prevent their distribution in new areas.

## Keywords

Urban green system, ecosystem services, Unmanned aerial vehicles (UAV), phytosanitary status

## Introduction

Urbanisation and urban growth are major drivers of ecosystem change globally (Wratten et al. 2013). Urban ecosystem concepts remind citizens and decision-makers that we all

ultimately depend on our ecosystems and their services (Daily et al. 1997). According to the Millennium Ecosystem Assessment, urban systems are considered as ecosystems necessary for human welfare (De Berg et al. 2005, Millennium Ecosystem Assessment 2003). To cope with the rapid inflow of people, cities need functional transportation systems, intelligent logistics and energy efficiency. All these people need an inclusive, healthy, resilient, safe and sustainable living environment, which provides a flow of a variety of ecosystem services (ES).

A wide debate has developed in Europe concerning the potential of green infrastructures (GI) for attaining goals going beyond the strict biodiversity targets, while maintaining the supply of ES, ecological connectivity, as well as concerning the valuation of ES for social, economic and business purposes. Urban green infrastructure (UGI) plays a vital part for any city in Europe, by providing a range of environmental, social, economic and cultural benefits.

Mapping and assessment of ecosystems and their services (MAES) are core to the EU Biodiversity (BD) Strategy, where Action 5 sets the requirement for an EU-wide knowledge base.

Knowledge about UGI is important for maintaining the quality of life in cities, suburbs and the fringes of metropolitan areas. The perspective of rapid urban sprawl generates the need to create a monitoring system on the condition of the urban ecosystems focusing on the condition of green spaces. This triggers the search for a stronger link between the condition of urban green infrastructure and its capacity to supply ES.

Understanding the condition of the urban green infrastructure is important for making informed decisions on maintaining or investing in it. The national process of mapping and assessment of urban ES in Bulgaria is ongoing and based on the elaborated methodological framework (Zhiyanski et al. 2017). The results obtained imply that additional measurements are needed in order to have a more accurate estimation of the real ES supply capacity of the urban green infrastructure in the regional context. An integrated approach for managing of GI has been developing in the EU framework by widening the narrow field for application of different assessment tools. Therefore, a GIS-based spatial planning decision support tool for assessing and evaluating existing green spaces is facilitating the application of the GI approach in strategic planning.

The solutions for revitalising UGI are to be found in a combination of scientific knowledge and innovative tools for the better assessment of the condition of urban green spaces (i.e. introducing measures to increase the ES supply) along with human ingenuity.

In this regard, the paper deals with presenting an integrated approach in assessing the UGI condition by *in-situ* observation and remote-sensing in selected urban ecosystems in Karlovo region.

## **Material and methods**

## Studied areas

Urban ecosystems correspond to the classes at first and second levels, as defined in MAES (Maes et al. 2013) and include urban, industrial, commercial and transport areas, urban green areas, mines, dumping and man-made sites. At the third level, the typology of urban ecosystems in Bulgaria corresponds to the National concept for spatial development for the period 2013-2025. Different types of urban ecosystems in Bulgaria are defined in Table 1.

The urban ecosystems in Karlovo are formed by seven types Fig. 1.

In this study, four areas of the urban territory of Karlovo were investigated: the area of 'Apostolova gora' park; the central part of the city; the 'Hunting' Park and the city stadium area; the area of 'Suchurum' waterfall (Northern Park). The selected areas include the most important elements of the town's green infrastructure (Fig. 2).

## In-situ observations

Two *in-situ* observations in the selected case-study sites were conducted during the periods 25-27 May and 7-8 July 2016 and a control observation of some individual trees in the central part of city was carried out on 9 August 2017. The health status of the vegetation was evaluated on ten individuals of each species (except in cases where the number of host plants was smaller) (Sinclair et al. 1987). The harmful effects and impact of arthropod pests (insects, mites) and fungal pathogens causing damage to green ecosystems were evaluated on the basis of the percentage of crown defoliation and discolouration of leaves or needles following the methodology of the International Co-operative Programme 'Forests' (Eichhorn et al. 2010). Defoliation as well as discolouration of crowns were estimated visually as the main parameters of the crown condition vitality. The estimated values were given in 5 classes from 0% (healthy tree) to 100% (dead tree), subdivided into five classes (Table 2).

Defoliation surveys were linked with detailed assessments of biotic and abiotic damage causes on leaves, stems, branches and young shoots. Other specific indicators were also recorded: presence of drying or rotted trees, endangering human life and health; insect attacks causing allergies; invasive species penetration; presence of trees colonised by highly aggressive xylophages or dangerous pathogens being a threat to the surrounding plants.

Determination of damage symptoms and causes (biological agents or abiotic factors) were implemented for studying of cause-and-effect mechanisms. For the purpose of this study, three categories of harmful effects caused by pests were determined according to the gradation of native species, detection of invasive alien species, range of trophic groups that pests belong to and the physiological state of host plants (Table 3). The reason for such categorisation is the fact that defoliations caused by phylophages could be overcome relatively easily at the expense of the reserve capacities. To their difference, the damage

on non-renewable and difficult-to-renew tissues and organs leads to a decline in the permanent health state and death of the infested trees (Georgiev et al. 2017). Concerning fungal pathogens causing damage to tree and shrub vegetation, three categories of harmful effects on the basis of pathogen virulence and aggression, physiological condition of host plants and opportunities for wide spreading of disease, were also suggested.

## Remote-sensing

Considering the role of the UGI for providing ES, the authors assessed the 'quality' of GI in selected case-study areas in Karlovo by a multispectral camera 'Parrot SEQUOIA'. The camera was integrated with a specialised professional UAV system of type 'Flying Wing', which provides the opportunity to collect specialised information about the state of GI in urban areas in an extremely effective way. The multispectral camera provides imaging of the studied area in 4 channels of the electromagnetic spectrum: G (**Green** corresponds to the reflected energy in the 530–570 nm spectral band), R (Red- reflected energy in the 640–680 nm spectral band), **Red Edge** (very narrow band between 730–740 nm, corresponding to the rapid change from low Red reflectance to high Near Infrared reflectance) and NIR (Near infrared- wavelengths in the 770 nm to 810 nm range). It has also a standard RGB channel. The camera was equipped with a solar radiation sensor which serves for calibration of the obtained reflex images.

For accomplishment of the assessment, NDVI (Normalised Difference Vegetation Index) was used, which was obtained by digital mixing of imagery, captured in the red and near-infrared (NIR) range and was calculated according to the following formula:

$$NDVI = (NIR - Red) / (NIR + Red)$$

NDVI is a simple graphical indicator used to assess whether the target being observed contains live green vegetation or not. The index is very helpful in the examination of the vitality of plants by capturing the amount of light which is being absorbed and reflected by them and the available chlorophyll I. NDVI itself varies between -1.0 and +1.0 and typically the green vegetation has values between 0.3 and 1. In general, if there is much more reflected radiation in near-infrared wavelengths than in visible wavelengths, then the vegetation in that pixel is likely to be dense and may contain some type of forest. Subsequent work has shown that the NDVI is directly related to the photosynthetic capacity and hence energy absorption of plant canopies (Myneni et al. 1995). Visualisation of the imaged area in a different colour range shows the vitality level of plants and clarifies where the plants are healthy and where additional care is needed.

The field mission was preceded by careful planning and drawing up of a precise flight plan. The missions' planning was performed using the SenseFly-E-motion specialised platform. Flights were planned in four selected areas of the urban territory of Karlovo (Fig. 2).

Imaging was performed with sensors for gathering of positioning and quality data (about the condition of the ecosystems) with the assistance of the professional UAV system eBee

that utilises photogrammetric and multispectral cameras. The gathered field information was processed by a specialised platform for photogrammetric processing Pix4D Professional Mapper.

The remote sensing was combined with an *in-situ* observation of the health status of tree vegetation and analyses of plant diversity.

## Results

### In-situ observations

As a result of the *in-situ* observations and assessment of the urban vegetation condition in selected areas in Karlovo, it was found that the city is characterised by a well-developed green infrastructure with a prevalence of native tree species. A total of 41 tree and shrub species were assessed for changes in crown defoliation and discolouration as a parameter of tree vitality. Twenty-eight of the species were deciduous and the remaining thirteen were conifers. The mean defoliation for all observed species ranges between 0% and 100% (Table 2). In good condition, with no symptoms of damage on any assessed sites, were trees of species *Ailanthus altissima*, *Abies alba*, *Cercis siliquastrum*, *Diospyros lotus*, *Fraxinus ornus*, *Tilia argentea*, *T. platyphyllos*, *Sambucus nigra* and *Sophora japonica*. Amongst the rest of the observed species, 32% were assessed as slightly defoliated, 48% were with moderate mean defoliation and 20% were severely defoliated (mean defoliation between 70-100%). Furthermore, it was observed that trees, evaluated as moderate and severe degrees, revealed damage caused by a number of different biotic, abiotic and anthropogenic factors. However, the assessment of health condition in different parks varied depending on site and tree specific conditions. Amongst the common groups of trees, the most severely affected were species from genera *Pinus* and *Ulmus*. Identified insects, diseases and other damaging agents that adversely affected the ability of green ecosystems of Karlovo to produce goods and services, were subdivided into three categories based on their harmful effects.

Eighteen insect species (Insecta) and one mite species (Arachnida) were established on forest trees and shrub species in urban systems of Karlovo (see Table 4). Eight of them belong to the first harmful category: four invasive species (*Cameraria ohridella*, *Cydalima perspectalis*, *Gilletteella cooleyi* and *Corythucha ciliata*), three destructive xylophagous species (*Zeuzera pyrina*, *Phaenops cyanea* and *Scolytus multistriatus*) and one species causing allergies (*Thaumetopoea pityocampa*). The second harmful category includes five species (*Pissodes* sp., *Phyllonorycter platani*, *Gossyparia spuria*, *Monochamus galloprovincialis* *pistor* and *Psylla buxi*) and the third category – six species (*Tetraneura ulmi*, *Aegosoma scabricorne*, *Cerambix cerdo*, *C. scopoli*, *Rhagium inquisitor* and *Eriophyes tristriatus*).

Twenty-five pathogen species were identified as causal agents of biotic damage (see Table 4). Amongst them, seven species belong to first harmful category - six strongly pathogenic

and invasive species (*Allantophomopsis pseudotsugae*, *Botryosphaeria dothidea*, *Cryptostroma corticale*, *Diplodia sapinea*, *Dothistroma pini* and *Ophiostoma novo-ulmi*) and two fungi endangering human health and life (*C. corticale* and *Phellinus igniarius*). The rest of the identified pathogens were divided into a second harmful category because of their local influence on host plants' leaves or needles. Saprophyte fungi, belonging to the third harmful category, were not observed on dead plants.

Amongst conifers, pine trees displayed the highest mean defoliation in 'Apostolova gora' and central parks. In 'Apostolova gora' park, all pine trees showed severe defoliation (50-90%) due to a combined attack by pests and pathogens belonging to the first harmful category. Insect pests were the predominant identified cause of this damage. The most dangerous species was the buprestid *Phaenops cyanea* on *Pinus nigra* and *P. radiata* (Fig. 3). Fungal pathogens were the second major causal agent group affecting all assessed pine trees causing needle and shoot blight diseases. The invasive pathogenic fungi *Dothistroma pini* and *Diplodia sapinea* affected *P. nigra*, *P. radiata* and *P. strobus* and caused an unattractive environment and degradation of ecosystems in the urban landscape. The third major identified cause of damage to pine trees was abiotic and anthropogenic agents. Drought periods within the observed two growing seasons additionally led to worsening of the tree physiology in the second year in such a way that they became more vulnerable to pest attack which caused severe damage and death to trees. In 2016, the mean defoliation of *P. radiata* trees in the central part of the city was assessed between 40 and 70%. The main causal agents and factors responsible for the observed damage symptoms were the pests *P. cyanea*, *Pissodes* sp., *M. galloprovincialis* *pistor*, *R. inquisitor* and development of the invasive strongly pathogenic fungi *D. pini* and *D. sapinea* (first harmful category). In 2017, a control observation of *P. radiata* trees revealed that almost half of the trees were completely dead and the rest were dying with defoliation 70-90%, heavily affected by the coincident development of the pests and pathogens (Fig. 4).

All observed elm trees (*Ulmus minor*) in the central and 'Hunting' parks were attacked by the invasive pathogen *Ophiostoma novo-ulmi* which caused one of the most destructive diseases – Dutch elm disease, distributing along vascular tissues, which significantly disturbed the balance of the tree water and caused tracheomycotic damage, severe wilting and tree mortality (first harmful category). During the first observation in the central parks (May 2016), only slight symptoms of the disease were recorded. Two months later (July 2016), the proportion of declined elm trees, as well as their defoliation, significantly increased (Fig. 4). The crowns of infected trees were covered by withering leaves which remained on the branches. The results obtained in the control survey (August 2017) revealed that all trees infected by the fungus in the previous year were completely dead and the population density of the pathogen's vector (*S. multistriatus*) was extremely high (Table 4).

Concerning established dangerous phytophagous insects from the first harmful category (*C. ohridella*, *C. perspectalis*, *G. cooleyi*, *C. ciliata* and *T. pityocampa*), the impact on observed hosts was not significant due to their low density.

Two introduced invasive fungal pathogens were detected and these caused significant damage and a negative influence on tree vitality - *Botryosphaeria dothidea* detected on *Sequoia sempervirens* and *Juniperus virginiana* in the observed central parks and *Cryptostroma corticale* observed on drying and completely dead trees of *Acer pseudoplatanus* in the central and 'Hunting' parks.

Development of timber-destructive fungi on tree stems and branches endangering human life and health (first harmful category) was observed on *Salix babylonica* trees along the 'Stara reka' river in the area of 'Suchurum' waterfall park.

Fungal pathogens, belonging to the second harmful category and causing local, non-aesthetic damage to green vegetation used for planting, were determined in all selected case-study areas. On the leaves of horse chestnut (*A. hippocastanum*), the invasive species *Phyllosticta paviae* had developed together with the leaf mining moth (*C. ohridela*). Pathogens from genera *Lophodermium* were detected on needles of *Pinus* spp. and *Picea abies* and caused slight defoliation of crowns.

Mechanical damage made by persons working or visiting the parks was observed on single trees in all selected sites. Wounding of trees initiated the process and led to their decay and death. During the *in-situ* observation conducted on 25 May 2016, very strong winds passed through the city and broke off brittle branches of *Acer dasycarpum* in 'Suchurum' waterfall park, resulting in threats for human injury or death.

## Remote sensing

The territory of 'Apostolova gora' park has been captured with 1008 individual images, covering 62.9 ha with an average resolution of 13.2 cm. A view of the 4 captured channels and the generated Digital Surface Model is shown in Fig. 5. After processing of the base products (images and Digital Surface Model), the NDVI model for the territory was created (Fig. 6).

The map clearly shows the areas with a high value of vitality of vegetation cover, as well as those with a lack of vegetation cover and vegetation in an unsatisfactory condition. In almost 50% of the studied area, the vegetation index is more than 0.75, but in the park territory, relatively large areas can be seen with poor vegetation and the corresponding NDVI index values lie between 0.6 and 0.7.

The territory of the central part of the city has been captured with 1004 individual images, covering 61.2 ha with an average resolution of 13.2 cm. A view of the 4 captured channels and the generated Digital Surface Model is shown in Fig. 7. After processing of the base products (images and Digital Surface Model), the NDVI model for the examined territory was created (Fig. 8).

Generally, in this part of the urban area of Karlovo, the elements of green infrastructure are the most fragmented and have the smallest coverage. More than 50% of the territory

represents embedded and built-up areas without vegetation cover. Only about 15% of the central part of the city has an NDVI index more than 0.75.

The 'Hunting' park and the city stadium area have been captured with 852 individual images, covering 33.6 ha with an average resolution of 13.75 cm (Fig. 9). After the processing of the base products (images and Digital Surface Model), the NDVI model was created (Fig. 10).

Around 20% of the examined territory has NDVI indices above 75% which is due to the large areas with green infrastructure and good vitality of the vegetation. Data analysis shows that, in the 'Hunting' park, there are areas with a low level of plant vitality, corresponding to a low level of chlorophyll content.

The area of 'Suchurum' waterfall in Karlovo has been captured with 860 individual images, covering 51.2 ha with an average resolution of 15.1 cm (Fig. 11). After processing of the base products (images and Digital Surface Model), the type of NDVI model for the examined territory was created (Fig. 12).

The examined area is characterised by the relatively good condition of the green system. For more than 40% of the whole territory, the index values above 0.7 were calculated. These values show a high level of plant vitality and relatively good spatial coverage.

## Discussion

In the present research, the two approaches (*in-situ* observation and UAV-based remote sensing technology) were used in an integrated way to assess the vegetation condition for different types of functional sub-zones of the urban system for the town of Karlovo park, urban forest, sport area and town centre. *In-situ* observations included assessments of crown defoliation and changes in foliar discolouration as indicators of the health of the tree. These indicators are indicative of the presence of damaging biotic or abiotic agents that manifest through changes in crown condition (Ferretti 1997). The health status of tree vegetation was evaluated using a remote sensing approach and was used to track the spread of disease and to monitor changes in tree health in studied areas. This technology provides tree health information that is fundamental for analysing the environmental, social and economic services produced by urban forests and allows experts to identify the location of unhealthy trees for further diagnosis and treatment (Hall et al. 2016). However, the benefits derived from using remote sensing techniques will arise not from assessment of individual trees, but from determining the average infection, or crown condition, over a particular area (Bulman et al. 2005, Tuominen et al. 2009). The Normalised Difference Vegetation Index (NDVI) is widely used for the detection of the greenness or health condition in forest and urban ecosystems (Xiao and McPherson 2005).

In studied green systems of Karlovo, the vitality of the vegetation cover in NDVI models fully corresponds to the obtained *in-situ* results. In 'Apostolova gora' park, the areas with relatively low index of *Pinus nigra* are due to the impact of native buprestid *Phaenops cyanea* which is one of the most destructive xylophagous pests in pine plantations in



Bulgaria (Mirchev et al. 2016). The buprestid larvae develop between the bark and sapwood, damaging the phloem, which leads to rapid weakening and destruction of the attacked trees. Pest outbreaks, appearing over the area of the park, were dynamic and changed even within a single growing season. The expansion of invasive pathogens *Diplodia sapinea* and *Dothistroma pini* additionally threatened the pine species in the park and caused unattractive environment and ecosystems degradation.

The central area of Karlovo represents the most fragmented and built-up areas with relatively small parks scattered throughout the centre. The vegetation covers about 38% of the territory. The low value of the NDVI index indicates that there are areas with a low level of plant vitality, corresponding to a low level of chlorophyll content, diseased, foliage damaged and water stressed vegetation. In this area, the most aggressive invasive pest and pathogens were detected. Recently penetrative invasive alien insects such as *Cameraria ohridella*, *Corythucha ciliata*, *Cydalima perspectalis* and *Gilletteella cooleyi* could be the greatest threat to the tree and shrub vegetation. They had a low population density at the time of study (end of May – beginning of July), but they are polyvoltine species that grow in numbers during the vegetation period. *C. ohridella* was first established in Bulgaria at the end of 1980s (Pelov et al. 1993) but currently it is widespread in the country, causing significant damage to *Aesculus hippocastanum*. The Nearctic *C. ciliata* was found for the first time in Bulgaria in 1989 (Josifov 1990) and, to the present time, it is distributed throughout the country on *Platanus* spp. Another species of *Corythucha* genus, *C. arcuata* (Say) was also reported in Bulgaria as the pest of oaks (*Quercus* spp.) (Dobрева et al. 2013) but it was not found in this study. The Asian *C. perspectalis* was found in Bulgaria in 2013 (Beshkov et al. 2015). Now it is widely distributed as a destructive pest of *Buxus sempervirens* in many regions of the country, including Karlovo. The Nearctic species *G. cooleyi* is the most dangerous insect pest on Douglas fir (*Pseudotsuga menziesii*) in Europe. It was first established in Bulgaria in 1989 (Tsankov et al. 1990) but nowadays, it is widely distributed in the country. The species develops several generations per year and forms colonies of different densities after mid-May.

A low population density was also established for *T. pityocampa*, but the occurrence of the species in urban parks, schoolyards and recreational forests had a hazardous effect due to its potential to cause an allergic and toxic reaction in human and animals. The species is distributed in the southern part of the country, including Karlovo region in central southern Bulgaria. During the last 10-15 years, *T. pityocampa* expanded its range to the east passing from Karlovo kettle to Kazanluk, with an annual spread of 2-3 km (Georgiev et al. 2017).

Deterioration of all *Pinus nigra* and *P. radiata* trees occurred in the central area of Karlovo city and was due to the development of two invasive pathogens *D. sapinea* and *D. pini*. In recent years, the pathogens have developed a strong virulence and have caused serious damage to local and introduced pine species throughout the country, affecting negatively their growth and aesthetic qualities and finally have resulted in the complete death of trees (Georgiev et al. 2017).

The new introduced invasive pathogens - *Botryosphaeria dothidea* (Georgieva, 2017) and *Cryptostroma corticale* (Bencheva 2014) were detected causing significant damage and having negative influences on the tree vitality of host trees in the Central park. The aggressive nature of the pathogens is manifested by non-renewable damage which they cause on stems and branches of infected trees. In addition, *C. corticale* also has the ability to cause adverse health effects on humans. Breathing of large amount of spores produced by the fruit bodies could lead to breathing difficulties and lung inflammation (Douzon 2007). The pathogen *B. dothidea* is widely distributed in city parks in the country where *Sequoia sempervirens*, *Sequoiadendron giganteum* and *Juniperus virginiana* were used as ornamental exotic species (Georgieva 2017).

Elm (*Ulmus minor*) trees are commonly planted along streets and urban green areas in Karlovo. The development of a severe invasive infection of pathogen *Ophiostoma novo-ulmi* into the vascular system of infected trees led to their decline and complete death in a year. This was observed in Central and 'Hunting' parks. The increased progression of this disease was influenced by the successful interactions between the pathogen and reproductive characteristics of the insect-vector, the elm bark beetle (*Scolytus multistriatus*). As many of the affected trees grow along street trees and central parks, the activity of this pathogen has resulted in a risk to public safety and dead wood has to be removed before it becomes an unacceptable hazard.

The examined area of 'Suchurum' waterfall park is characterised by the relatively good condition of the green system. For more than 40% of the whole territory, the index values above 0.7 were calculated, indicating a high level of plant vitality and relatively good spatial coverage. However, the established fruit bodies of the timber destructive fungus *Phellinus igniarius* on *Salix babylonica* trees, growing along 'Stara reka' river, indicate a progressive development of the rotting process. Rotted stems and branches decrease the mechanical resistance of tissue and create preconditions for their breaking, which endangers human life and health in cases of severe storms and heavy snowfalls.

## Conclusions

Assessment of the health status of tree and shrub vegetation in urban ecosystems of Karlovo through in-situ observation and remote sensing technology was used for the first time in Bulgaria. The results showed that the implementation of this integrated approach could be used extensively for remote monitoring of green systems in settlements with subsequent detailed investigation of solitary trees for cataclysms and epiphytotics of native species and rapid detection of populations of invasive insects and pathogens in order to prevent their distribution in new areas.

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## Conflicts of interest

We declare no conflict of interest.

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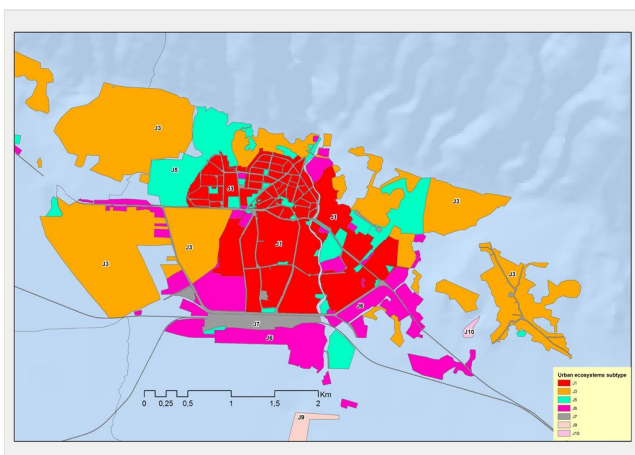


Figure 1.  
Spatial distribution of urban ecosystems in Karlovo (Urban ecosystem subtypes codes are explained in Table 1).

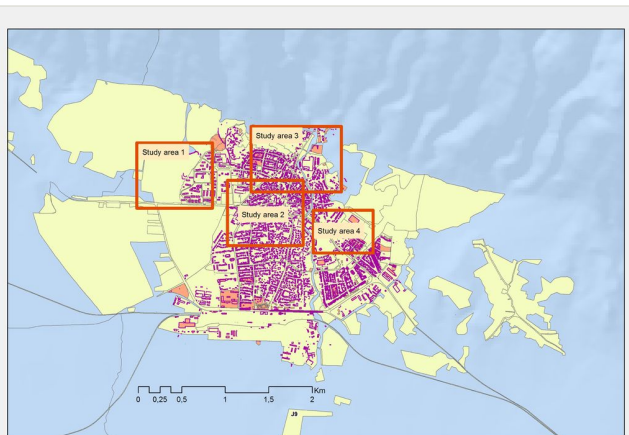


Figure 2.  
Studied areas in Karlovo municipality.



Figure 3.

Damage on *Pinus nigra* and *P. radiata* caused by *Phaenops cyanea*: A – larval galleries (Apostolova gora park, 26 May 2016); B – exit holes of adults (Central park, 9 August 2017); C – weakened and dead trees (Central park, 9 August 2017).

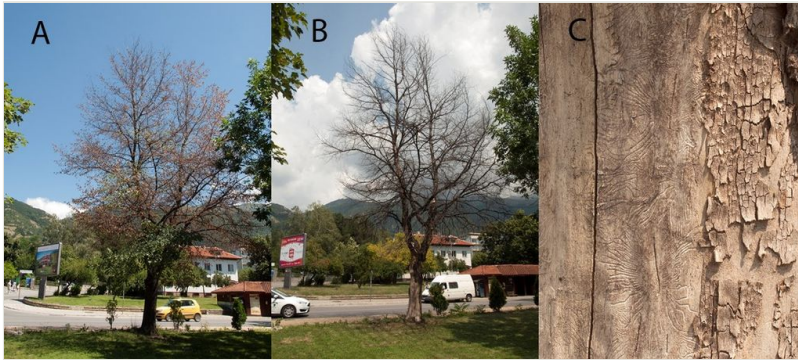


Figure 4.

Damage on *Ulmus minor* caused by *Ophiostoma novo-ulmi* in Central park: A – dying tree (8 July 2016); B – dead tree (9 August 2017); C – galleries of elm bark beetle, *Scolytus multistriatus* (9 August 2017).



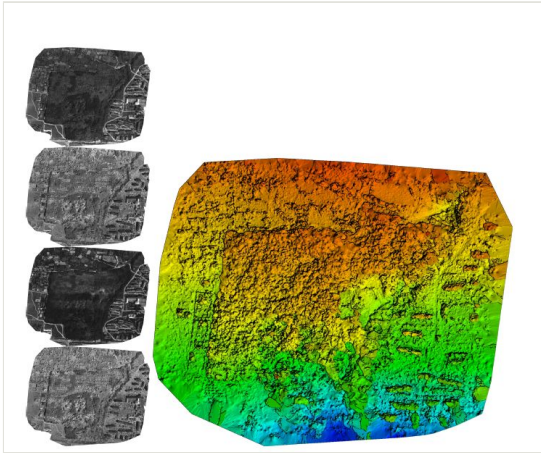


Figure 5.  
Digital Surface Model of 'Apostolova gora' park.

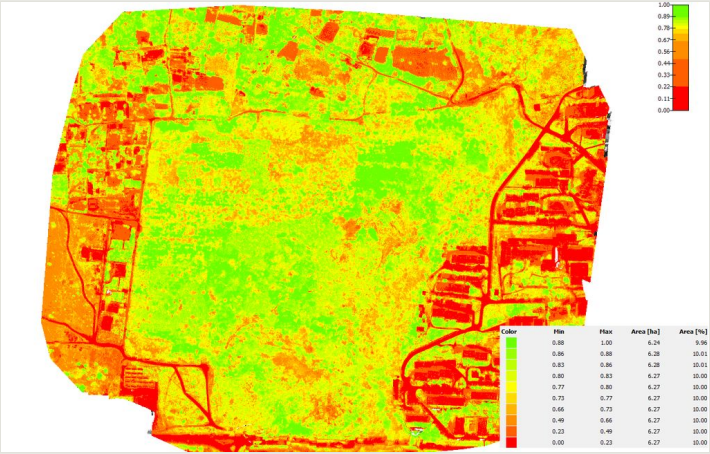


Figure 6.

NDVI model of 'Apostolova gora' park (Min- minimal NDVI score for the class, max-maximal NDVI score for the class, area (ha) total area of the NDVI class, area (%)- relative share of the NDVI class within the studied area).

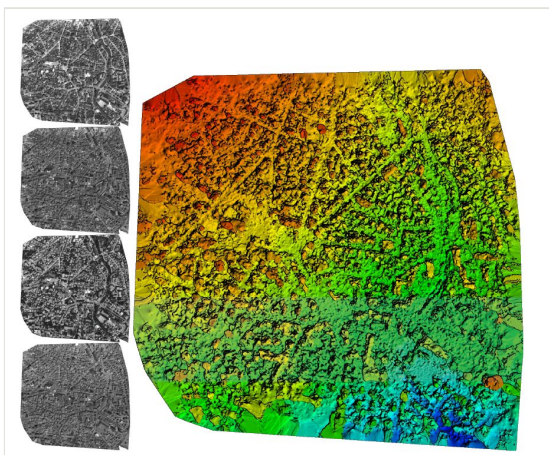


Figure 7.  
Digital Surface Model of the central part of Karlovo.

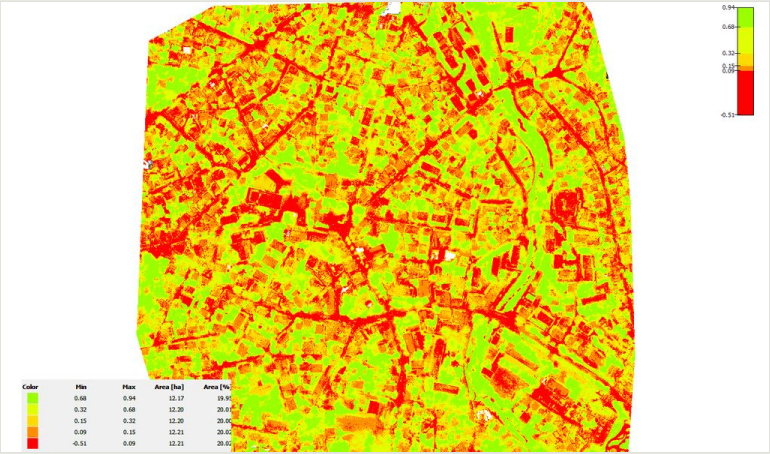


Figure 8.

NDVI model of the Central park of Karlovo (Min- minimal NDVI score for the class, max-maximal NDVI score for the class, area (ha) total area of the NDVI class, area (%)- relative share of the NDVI class within the studied area).

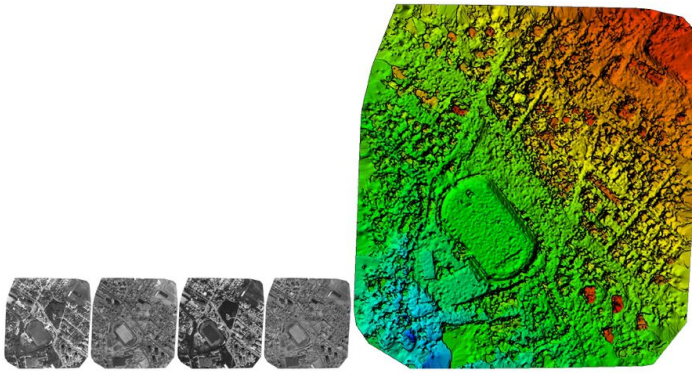


Figure 9.  
Digital Surface Model of 'Hunting' park and city stadium area of Karlovo.

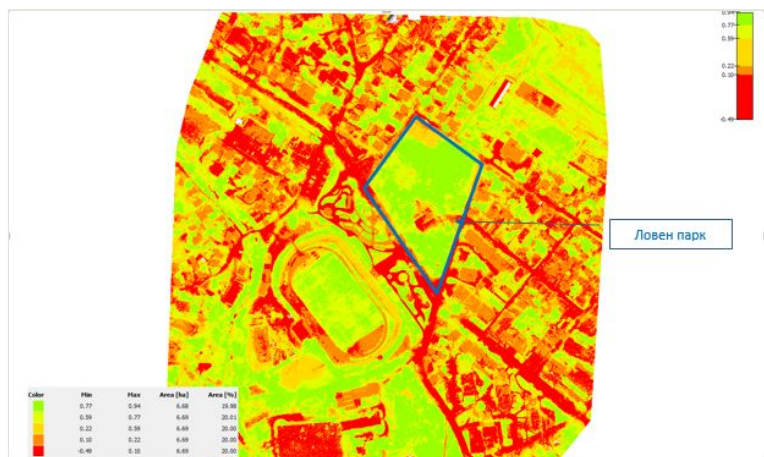


Figure 10.

NDVI model of 'Hunting' park and city stadium area of Karlovo (Min- minimal NDVI score for the class, max-maximal NDVI score for the class, area (ha) total area of the NDVI class, area (%)- relative share of the NDVI class within the studied area).

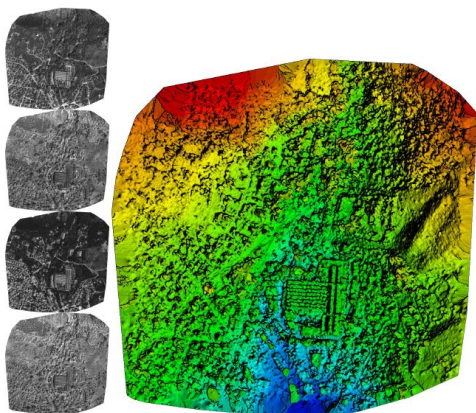


Figure 11.

Digital Surface Model of the area of 'Suchurum' waterfall in Karlovo.

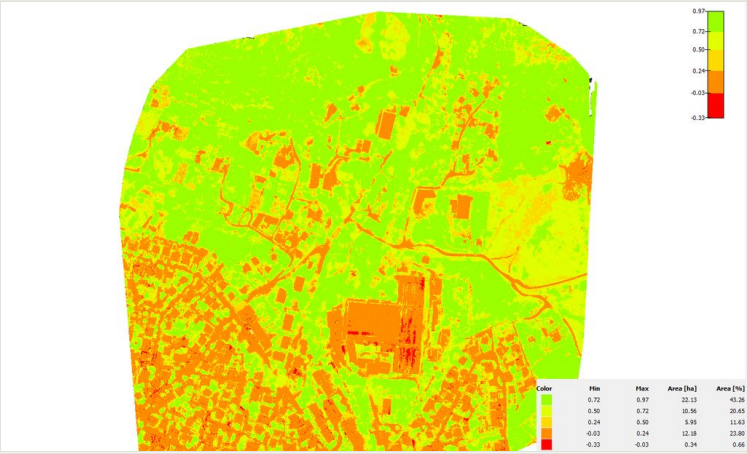


Figure 12.

NDVI model of the area of ‘Suchurum’ waterfall in Karlovo (Min- minimal NDVI score for the class, max-maximal NDVI score for the class, area (ha) total area of the NDVI class, area (%)- relative share of the NDVI class within the studied area).



Table 1.  
Typology of urban ecosystems in Bulgaria.

Level 1	Level 2	Level 3
Terrestrial	Urban	J1. Residential and public areas of cities and towns
		J2. Sub-urban areas
		J3. Residential and public low density areas
		J4. Recreation area outside cities and towns
		J5. Urban green areas (incl. sport and leisure facilities)
		J6. Industrial sites (incl. commercial sites)
		J7. Transport networks and other constructed hard surfaced sites
		J8. Extractive industrial sites (incl. active underground mines and active opencast mineral extraction sites a
		J9. Waste deposits
		J10. Highly artificial man-made waters and associated structures

Table 2.

Defoliation classes of tree and shrub crowns.

Defoliation class	Needle/leaf loss	Degree of defoliation
0	up to 10%	none
1	>10–25%	slight
2	>25–60%	moderate
3	>60<100%	severe
4	100%	dead

Table 3.

Harmful effects' categories of phytophagous arthropods and fungal pathogens in urbanised territories.

Category	Phytophagous arthropods	Fungal pathogens
I	<ul style="list-style-type: none"> <li>· destructive invasive species</li> <li>· rhizo-, xylo- and stolophages, developing cataclysms and attacking physiologically healthy trees</li> <li>· insects causing severe allergies</li> </ul>	<ul style="list-style-type: none"> <li>· strongly pathogenic fungi, incl. invasive species</li> <li>· fungi causing system diseases</li> <li>· fungi endangering human health</li> <li>· timber-destructive fungi</li> </ul>
II	<ul style="list-style-type: none"> <li>· xylophages which do not reproduce massively but are vectors for dangerous diseases on physiologically healthy trees</li> <li>· cataclysmic xylophages attacking weakened trees accelerating their ruin</li> <li>· cataclysmic phylophages</li> </ul>	<ul style="list-style-type: none"> <li>· fungi causing local diseases</li> <li>· fungi worsening tree and shrub ornamental qualities</li> </ul>
III	<ul style="list-style-type: none"> <li>· low number and rare species</li> </ul>	<ul style="list-style-type: none"> <li>· saprophyte fungi</li> </ul>

Table 4.

Phytosanitary characteristics of studied vegetation.

Vegetation species	Pests (Harmful category)	Pathogens (Harmful category)	Other specific indicators	Mean defoliation
<b>Apostolova gora park – J4</b>				
<i>Pinus nigra</i> Arn.	<i>Phaenops cyanea</i> Fabricius (I) <i>Pissodes</i> sp. (II) <i>Monochamus galloprovincialis</i> pistor Germar (II) <i>Rhagium inquisitor</i> Linnaeus (III)	<i>Diplodia sapinea</i> (Fr.) Fuckel (I) <i>Lophodermium pinastri</i> Schrad. ex Fr (II) <i>Lophodermium seditiosum</i> Minter (II) <i>Cyclaneusma niveum</i> (Pers.) DiCosmo, Peredo & Minter. (II)		70%
<b>Central park - J5</b>				
<i>Ailanthus altissima</i> Swingle				0%
<i>Acer negundo</i> L.				20%
<i>Acer pseudoplatanus</i> L.		<i>Cryptostroma corticale</i> (Ellis & Everh.) (I)		90%
<i>Abies alba</i> Mill.				0%
<i>Betula pendula</i> Roth				70%
<i>Buxus sempervirens</i> L.	<i>Psylla buxi</i> L. (II)	<i>Volutella buxi</i> (DC.) Berk. (II) <i>Macrophoma candollei</i> (Berk. & Broome) Berl.& Voglino (II)		60%
<i>Castanea sativa</i> Mill.		<i>Mycosphaerella maculiformis</i> (II)		20%
<i>Catalpa bignonioides</i> Walter		<i>Erysiphe elevata</i> (Burr.) Braun (II)		20%
<i>Cedrus atlantica</i> (Endl.) Manetti ex Carrière		<i>Botrytis cinerea</i> Pers. (II) <i>Sirococcus conigenus</i> (II)		50%
<i>Diospyros lotus</i> L.				0%
<i>Fraxinus ornus</i> L.				0%
<i>Fraxinus angustifolia</i> Vahl.	<i>Zeuzera pyrina</i> Linnaeus (I)			20%

<i>Ginkgo biloba</i> L.				0%
<i>Juniperus virginiana</i> L.		<i>Botryosphaeria dothidea</i> (Moug. ex Fr.) Ces. & De Not. (I)		30%
<i>Picea excelsa</i> L.		<i>Lophodermium piceae</i> (Fuckel) Höhn. (II)		20%
<i>Picea pungens</i> Engelm.			mechanical damage	80%
<i>Pinus nigra</i> Arn.		<i>Diplodia sapinea</i> (Fr.) Dyko & Sutton. (I)		40%
<i>Pinus radiata</i> Don.	<i>Phaenops cyanea</i> Fabricius (I) <i>Pissodes</i> sp. (II) <i>Monochamus galloprovincialis</i> pistor Germar (II) <i>Rhagium inquisitor</i> Linnaeus (III)	<i>Dothistroma pini</i> Hulbary (I) <i>Diplodia sapinea</i> (Fr.) Dyko & Sutton. (I)		50%
<i>Pinus strobus</i> L.		<i>Diplodia sapinea</i> (Fr.) Dyko & Sutton. (I)		25%
<i>Platanus acerifolia</i> Willd	<i>Corythucha ciliata</i> Say (I) <i>Phyllonorycter platani</i> (Staudinger) (II)	<i>Apiognomonina veneta</i> (Sacc. & Speg.) Höhn. (II) <i>Cytospora platani</i> Fuckel (II)		20%
<i>Quercus rubra</i> L.		<i>Apiognomonina veneta</i> (Sacc. & Speg.) Höhn. (II)		20%
<i>Salix babylonica</i> L.				20%
<i>Sequoia sempervirens</i> (D.Don) Endl.		<i>Botryosphaeria dothidea</i> (Moug. ex Fr.) Ces. & De Not. (I)		30%
<i>Taxus baccata</i> L.				30%
<i>Thuja occidentalis</i> L.		<i>Kabatina thujae</i> R. Schneid. & Arx (II) <i>Pestalotiopsis funerea</i> (Desm.) Steyaert (II)		50%
<i>Tilia argentea</i> Desf ex DC				0%
<i>Ulmus minor</i> Mill.	<i>Scolytus multistriatus</i> (Marsham) (I) <i>Gossyparia spuria</i> Modeer (II) <i>Tetraneura ulmi</i> Linnaeus (III)	<i>Ophiostoma novo-ulmi</i> Buism. (I)		50%
'Suchurum' waterfall park - J5				

<i>Abies concolor</i> (Gord. & Glend.) Lindl)				100%
<i>Acer campestre</i> L.				10%
<i>Acer dasycarpum</i> Ehrh.				30%
<i>Acer palmatum</i> (Thunb.) not Raf.				15%
<i>Acer</i> <i>pseudoplatanus</i> L.		<i>Rhytisma acerinum</i> Schwein. (II)		30%
<i>Aesculus</i> <i>hippocastanum</i> L.	<i>Cameraria ohridella</i> Deschka & Dimić (I)	<i>Phyllosticta paviae</i> Desm. (II)		30%
<i>Ailanthus altissima</i> Swingle				0%
<i>Alnus glutinosa</i> (L.) Gaertner		<i>Pseudomonas</i> sp.		70%
<i>Buxus</i> <i>sempervirens</i> L.	<i>Cydalima perspectalis</i> Walker (I)	<i>Volutella buxi</i> (DC.) Berk. (II)		50%
<i>Castanea sativa</i> Mill.	<i>Aegosoma scabricorne</i> Scopoli (III) <i>Cerambyx cerdo</i> Linnaeus (III)	<i>Mycosphaerella maculiformis</i> (Pers.) Schröt (II)		30%
<i>Catalpa</i> <i>bignonioides</i> Walter		<i>Erysiphe elevata</i> (Burr.) Braun (II)		20%
<i>Cedrus atlantica</i> (Endl.) Manetti ex Carrière				15%
<i>Diospyros lotus</i> L.				0%
<i>Fraxinus excelsior</i> L.	<i>Zeuzera pyrina</i> Linnaeus (I)			30%
<i>Juglans regia</i> L.	<i>Eriophyes tristriatus</i> (Nalepa) (III) <i>Cerambyx</i> <i>scopoli</i> Fuessly (III)	<i>Melanconis juglandis</i> (Ellis & Everh.) Groves. (II)		80%
<i>Picea excelsa</i> L.		<i>Lophodermium piceae</i> (Fuckel) Höhn. (II)		15%

<i>Pinus nigra</i> Arn.	<i>Thaumetopoea pityocampa</i> Denis & Schiffermüller (I)	<i>Diplodia sapinea</i> (Fr.) Dyko & Sutton. (I) <i>Lophodermium pinastri</i> Schrad. ex Fr. (II) <i>Lophodermium</i> <i>sediciosum</i> Minter (II) <i>Cyclaneusma</i> <i>niveum</i> (Pers.) DiCosmo, Peredo & Minter. (II)	40%
<i>Platanus acerifolia</i> Willd	<i>Corythucha ciliata</i> Say (I) <i>Phyllonorycter platani</i> (Staudinger) (II)	<i>Apiognomonina veneta</i> (Sacc. & Speg.) Höhn (II) <i>Cytospora platani</i> Fuckel (II)	25%
<i>Pseudotsuga</i> <i>menziesii</i> (Mirb.) Franco	<i>Gilletteella cooleyi</i> Gillette (I)	<i>Allantophomopsis pseudotsugae</i> (Wilson) Nag Raj (I)	30%
<i>Quercus rubra</i> L.		<i>Apiognomonina veneta</i> (Sacc. & Speg.) Höhn (II)	30%
<i>Salix alba</i> L.		<i>Phellinus igniarius</i> (L. et Fr.) Quel. (I)	50%
<i>Salix babylonica</i> L.		<i>Phellinus igniarius</i> (L. et Fr.) Quel. (I)	20%
<i>Sambucus nigra</i> L.			0%
<i>Sequoia</i> <i>sempervirens</i> (Don) Endl.		<i>Botryosphaeria dothidea</i> (Moug. ex Fr.) Ces. & De Not. (I)	90%
<i>Sophora japonica</i> L.			0%
<i>Thuja occidentalis</i> L.		<i>Kabatina thujae</i> Schneid. & Arx (II) <i>Pestalotiopsis funerea</i> (Desm.) Steyaert. (II)	30%
<i>Tilia platyphyllos</i> Scop.			0%
<i>Ulmus minor</i> Mill.	<i>Tetraneura ulmi</i> Linnaeus (III)	<i>Ophiostoma novo-ulmi</i> Buism. (I)	30%
<b>'Hunting' park - J5</b>			
<i>Aesculus</i> <i>hippocastanum</i> L.	<i>Cameraria ohridella</i> Deschka & Dimić (I)	<i>Phyllosticta paviae</i> Desm. (II)	30%
<i>Acer</i> <i>pseudoplatanus</i> L.		<i>Cryptostroma corticale</i> (Ellis & Everh.) Greg. & Waller. (I)	40%

<i>Cedrus atlantica</i> (Endl.) Manetti ex Carrière				40%
<i>Cercis</i> <i>siliquastrum</i> L.				0%
<i>Juglans regia</i> L.	<i>Eriophyes tristriatus</i> (Nalepa) (III)			15%
<i>Fraxinus</i> <i>angustifolia</i> Vahl				0%
<i>Pinus nigra</i> Arn.	<i>Thaumetopoea pityocampa</i> (Denis & Schiffemüller) (I)	<i>Diplodia sapinea</i> (Fr.) Dyko & Sutton (I)		90%
<i>Tilia argentea</i> Desf ex DC				0%
<i>Ulmus minor</i> Mill.	<i>Scolytus multistriatus</i> (Marsham) (I)	<i>Ophiostoma novo-ulmi</i> Buism. (I)		95%