Integrated approach for health status assessment of urban forests in the municipalities of Etropole and Pravets, Bulgaria

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Abstract

In 2020, the health status of urban forests in Etropole and Pravets municipalities was monitored based on remote sensing data and field assessment. The study provides information for early detection and identification of pests and pathogens causing damage in different forest types. Three forest stands were assessed: Scots pine (*Pinus sylvestris*) plantation near the town of Etropole, European beech (*Fagus sylvatica*) natural stand near Etropole Monastery, and *Quercus* spp. coppice stands in 'Nebesnite Pasbishta' forest park near Osikovitsa village. In two sample plots (town of Etropole and Osikovitsa village), remote sensing data were obtained by a 'Parrot Sequoia' multispectral camera integrated with a specialized professional system eBee 'Flying Wing'. Normalised difference vegetation index (NDVI) was assessed by digital mixing of imagery, captured in the red and near-infrared range. It was established that the Scots pine plantations were weakened, with NDVI values between 0.66 and 0.75. The oak stands in the area of Osikovitsa village were in better health condition (NDVI mainly 0.79-0.98). Symptoms of diseases and pest damage were found during the field verifications. Severe deterioration caused by the invasive fungal pathogen *Dothistroma septosporum* had destroyed the pine plantation near Etropole. The pathogen caused premature needle defoliation, resulting in loss of timber yield and, in severe cases, tree death. In oak stands, damage was caused mainly by the invasive insect pest – oak lace bug (*Corythucha arcuata*). In *Fagus sylvatica* forests damage was caused mainly by abiotic factors (snow and wind), and wood destroying fungus *Fomes fomentarius*.

Keywords

urban forests, health condition, deterioration, biotic agents, Bulgaria

Introduction

In forest ecosystems in Bulgaria the most common pressures resulting in health status deterioration are caused by the defoliating insect pests *Lymantria dispar* (Linnaeus, 1758), *Thaumetopoea pityocampa* (Denis & Schiffermüller, 1775), leafrollers and geometer moths (Tortricidae and Geometridae), *Euproctis chryssorrhoea* (Linnaeus, 1758), pine sawflies (Diprionidae) (Mirchev et al., 2003; Zaemdzhikova et al., 2019). In urban territories, there are favourable conditions for development of helophytic and thermophilic insects in the areas, where plants are planted with larger growth space. In recent years, the trade, transport and tourism have facilitated the penetration of invasive species and formation of first outbreaks in and around the settlements (Georgiev et al., 2017). Currently, the introduced pathogens have turned into a growing threat for the natural plant species, disturbing the biodiversity and ecological dynamics in forest and urbanized ecosystems. Some destructive diseases caused by the invasive pathogens *Diplodia sapinea* (Fr.) Fuckel, *Dothistroma septosporum* (Dorogin) Morelet, *D. pini* Hulbary and *Lecanosticta acicola* (Thüm.) Syd., have affected the functional structure of pine forests in Bulgaria (Georgieva, Hlebarska, 2018; Georgieva, 2020; Zlatković et al., 2017). The emergence of new invasive diseases and pests in urban green areas have had a negative effect on the aesthetic vision of cities, and on the health and social status of residents and visitors (Georgiev et al., 2017).

In recent years, remote sensing techniques have provided information for detection of stressed forest stands induced by pests and diseases outbreaks. The assessment of vegetation health status in urban green areas by an unmanned aerial vehicle (UAV) and terrestrial verification was carried out for the first time in Bulgaria in the town of Karlovo (Dimitrov et al., 2018). The results showed that the implementation of this integrated approach was successfully used for remote monitoring of green systems in settlements with subsequent detailed investigation for calamities of insects and rapid detection of invasive pests and pathogens, in order to prevent their spreading in new areas. A number of remote sensing techniques became available to forest resource managers, supporting the planning procedures and monitoring the health status of the forest ecosystems (Dimitrov et al., 2019; Georgiev et al., 2022; Georgieva et al., 2022). Remote sensing-based images, indicating the presence of bark beetle attacks, could support the current monitoring practice by focusing the terrestrial search of infested trees to areas predicted as attacked.

The aim of the study was to assess the health status of forest stands in three urban areas in the region of Etropole and Pravets municipalities by applying the integrated approach of remote sensing methods and terrain validation, and to clarify the complex of main abiotic and biotic stressors responsible for forest stands deterioration.

Material and Methods

Study area

In September 2020, an area of 10.0 ha with forest stands situated in the town of Etropole (Etropole municipality) and Osikovitsa (Pravets municipality), were selected (Table 1): coniferous Scots pine (*Pinus sylvestris* L.) plantation near to the town of Etropole, an European beech (*Fagus sylvatica* L.,) natural stand near the Etropole Monastery, and an oak coppice stand (*Quercus cerris* L., *Q. frainetto* Ten., and *Quercus dalechampii* Ten.) in 'Nebesnite pasbishta' forest park, Osikovitsa village. The studied stands are situated in the urban area with a huge public importance, visited by many people.

Table 1. Characteristics of sample plots in studied forest stands

State Forestry	Location	Assessed area, ha	Tree species	Altitude, m a.s.l.	Geographical coordinates	
Etropole	Town of Etropole	3.50	*Pinus sylvestris*	523	N 42.852404	E 24.004138
Etropole	Etropole Monastery	3.25	*Fagus sylvatica*	795	N 42.823162	E 24.035303
Botevgrad	'Nebesnite pasbishta' forest park, Osikovitsa village	3.25	*Quercus frainetto Quercus dalechampii Quercus cerris*	455	N 42.925595	E 24.028846
	Total	10.0				

Forty sample plots (each of them with an area of 0.25 ha) were established (14 – in *P. sylvestris* plantation, 13 – in *F. sylvatica* natural stand, and 13 – in coppice forests with *Quercus* spp.). In each plot, 40 trees were selected for the assessment of their crown condition, and the damage caused by biotic and abiotic factors.

Remote sensing data

In this study, remote sensing data were obtained in two selected areas (Scots pine plantation – near the town of Etropole, and oak coppice stand – near Osikovitsa village). The 'Parrot Sequoia' multispectral camera, integrated with a specialized 'Flying Wing' professional system eBee 'Classic', was used to take high-resolution images in four channels of the electromagnetic spectrum: green (530-570 nm spectral band), red (640-680 nm), red edge (730-740 nm) and near infrared (770-810 nm), as well as in a standard RGB channel. The camera was equipped with a solar radiation sensor, which serves for the calibration of the obtained reflex images. The flights were carried-out on 21 October 2020, at an altitude of 120 m. The UAV-derived data was processed by a Pix4D platform and normalised difference vegetation index (NDVI) raster map of the captured areas. NDVI was calculated according to the following standard formula: (NIR-Red)/(NIR+Red). It varies between -1.0 and +1.0 and indicates the vegetation condition due to chlorophyll absorption of specific wavelengths of light within red spectral range and high reflectance within the NIR range. Visuali-

zation of the captured area in a different colour range shows the vitality level of forest trees. It indicates the area of healthy stands (NDVI most often over 0.7), trees infested by bark beetles (NDVI between 0.5 and 0.7) and bark beetle spots (NDVI below 0.5) (Georgiev et al., 2022).

Field study of health conditions

In the period 22-23 October 2020, field studies were carried-out for the evaluation of health status and assessment of the harmful effect of native and alien pests and disease in the studied areas. The crown condition of the trees was assessed according to the methodology of the International Cooperative Programme 'Forests' (Eichhorn et al., 2016). Two physiological indicators were included in the complex assessment of the trees: defoliation and discoloration. Defoliation of 1600 trees was estimated in 5% steps, ranging from 0% (no defoliation) to 100% (dead tree), grouped into five classes: '0' (0-10% – no defoliation); '1' (>10-25% – slight defoliation); '2' (>25-60% – middle defoliation); '3' (>60<100% – severe defoliation) and '4' (100% dead trees).

For the needs of this study, other indicators were taken into account: number of drying or rotting trees, endangering human life and health; presence of trees with symptoms of dangerous diseases or highly aggressive xylophages, which pose a threat to the surrounding plantations. The surveys were conducted with detailed identifications of biotic agents at the laboratories of phytopathology and entomology in Forest Research Institute – Sofia.

Results

Remote Sensing

The selected forest area on the territory of the town of Etropole and Osikovitsa village was captured. The land cover data around the urban areas showed that most forests were deciduous, represented mainly by beech and oak stands. Coniferous forests were predominantly plantations planted around the Etropole and Osicovitsa village.

The NDVI model analysis showed that the pine plantations situated near the town of Etropole were in deteriorated health status (Fig. 1). The pine trees were weakened (orange coloured), having NDVI values most often between 0.66 and 0.75. Inside the pine plantation there were many orange spots with NDVI values most often between 0.47 and 0.66.

The image in RGB colour clearly showed that the individual spots were essentially single dead pine trees or biogroups of drying trees with reduced vitality (Fig. 2).

The oak coppice stand in the area of Osikovitsa village were in a better health condition than the pine plantation in Etropole. With the exception of the unforested areas (coloured in orange and red, NDVI between 0.50 and 0.69), the captured forest areas have NDVI mainly between 0.79-0.98 (yellow and green coloured) (Fig. 3).
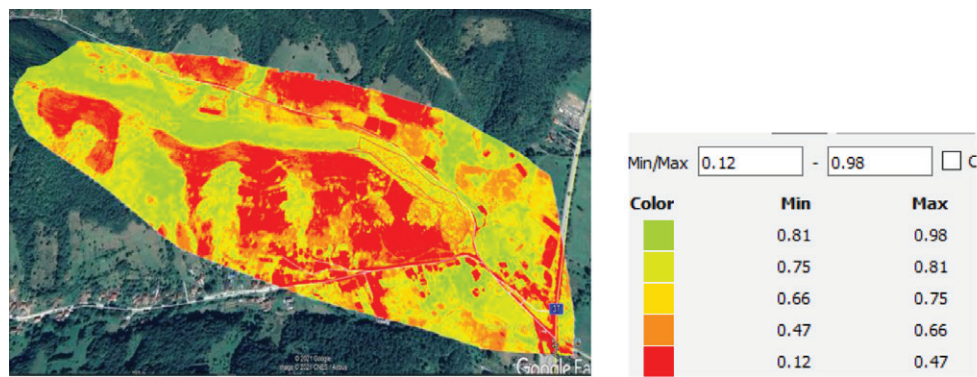
Figure 1. NDVI map of the sample plot close to the town of Etropole
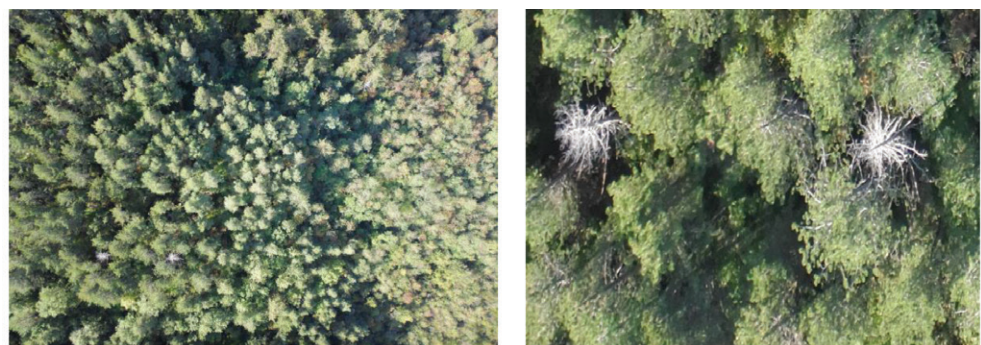

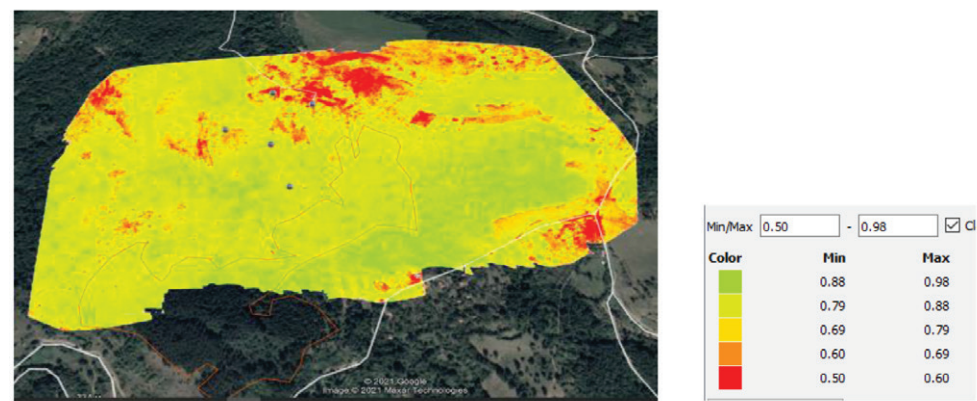**Figure 2.** Biogroups of drying trees and single dead trees near town of Etropole

Figure 3. NDVI map of the oak sample plot near Osikovitsa village

Field study of health conditions

A serious health status deterioration was noticed in the 560 assessed pine trees. The value of mean defoliation of all sample plots was 89.5%. Mean damage degree varied from '3' (severely damaged) at 75% of trees to '4' (dead) at rest trees (Fig. 4A). The results showed that symptoms of diseases and damage by insect pests caused the most significant impact on the process of drying.

The health status of trees in *Fagus sylvatica* stand was classified as 'very good' (Fig. 4B). Mean defoliations did not exceed 30%, the predominant degree of defoliation varied between 0 and 25%. Mean defoliation varied between 10.4% (no defoliated trees) and 25.8% (slightly defoliated trees).

Decline of single mature trees due to stem decay was observed in the oak stand. It was established that *Q. cerris* trees were not in good condition. The mean defoliation of all 520 sample trees varied from '1' slightly defoliated to '3' severely defoliated (Fig. 4C).

Identification of abiotic and biotic factors

Abiotic factors

Among the abiotic factors, significant damage was attributed to frost cracks, snow and drought damage. In *F. sylvatica* and *Quercus* spp. forests, the most significant damage was caused by frost cracks formed during the dormant season, when there was a sudden drop in temperature.

In the studied *P. sylvestris* plantation, the role of droughts during vegetation seasons determined the beginning of the drying process. It was also found that the increase in the age of trees is an essential reason for the worsening of their growth and vitality, especially in the areas outside of the species' natural habitats.

Biotic factors – fungal pathogens

Thirteen species of fungal pathogens, causing damage on needles, branches, stems and roots, were identified (Table 2). Because of the physiological weakening of pine trees, the invasive fungal pathogens *Dothistroma septosporum*, *Cyclaneusma minus* and *Diplodia sapinea* become devastating in the observed pine plantation. The presence of the root rot disease caused by *Heterobasidion annosum* was also established.

The alian fungal pathogen *D. septosporum* caused the most pathogenic damage on the pine trees near the town of Etropole (Fig. 5). The fungus caused needle blight disease – red coloured necrotic bands forming across the needles' length, and prematurely dropping of diseased needles. The symptoms were found on needles of all sample trees.

The second important pathogen responsible for the deterioration of the studied pine plantations was *Diplodia sapinea*. Damage was caused at the tip of the pine shoots, needles and on second-year cones. Withering of young needles altering the external portion of the crown, death of shoots and buds occurred in severe affected trees. It is an opportunistic pathogen, colonizing in weakened or dying woody trees.
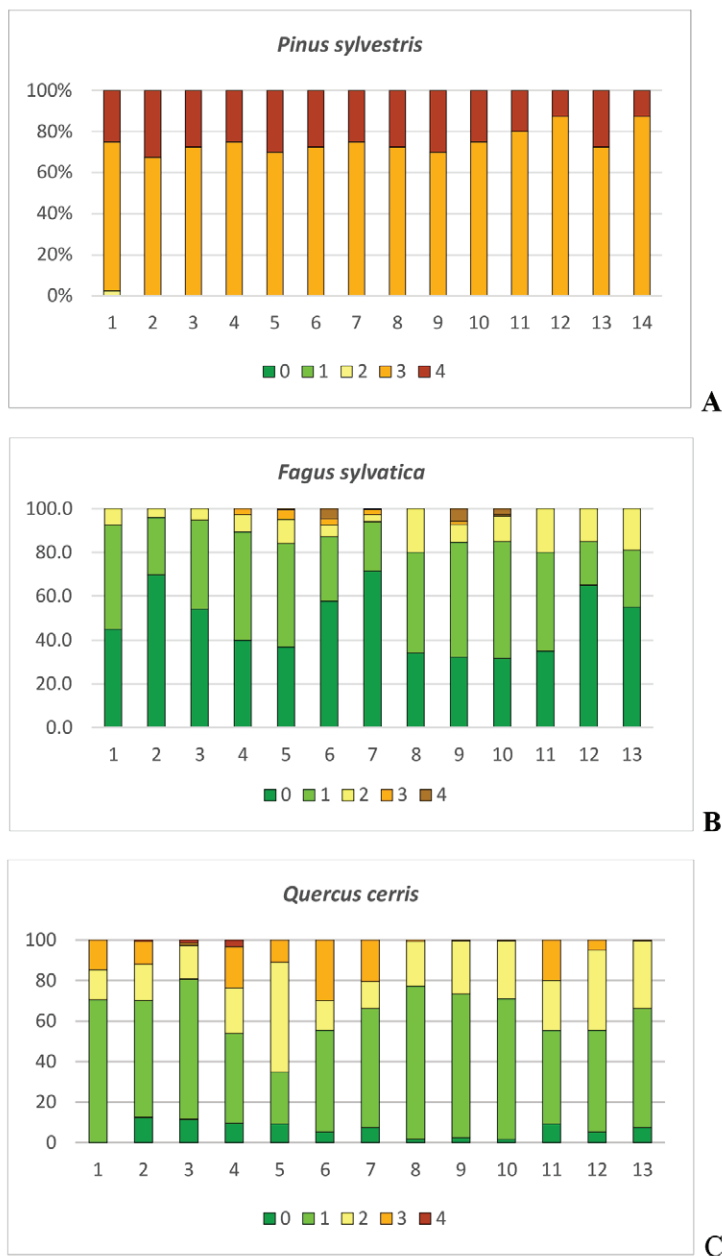
Figure 4. Figure 4. Assessment of health status of sample trees in observed plots: A – Pinus sylvestris; B – Fagus sylvatica; C – Quercus cerris

The results for *Fagus sylvatica* sample plots near Etropole Monastery showed damage caused by the wood-destroying fungal pathogen *Fomes fomentarius* (Table 2). Fruit bodies of the fungus were found most frequently on the trunks recently fallen by windthrow.

Figure 5. Deterioration of Scots pine plantations caused by fungal pathogen *Dothistroma septosporum*

Table 2. Fungal pathogens causing damage of trees in sample plots

N	Pathogens	Tree species	Affected parts	Significance
1	*Cyclaneusma minus*	*Pinus sylvestris*	needles	***
2	*Dothistroma septosporum*	*Pinus sylvestris*	needles	***
3	*Lophodermium pinastri*	*Pinus sylvestris*	needles	*
4	*Lophodermium seditiosum*	*Pinus sylvestris*	needles	*
5	*Sclerophoma pythiophila*	*Pinus sylvestris*	needles	*
6	*Cenangium ferruginosum*	*Pinus sylvestris*	shoots	**
7	*Diplodia sapinea*	*Pinus sylvestris*	shoots, cones	***
8	*Heterobasidion annosum*	*Pinus sylvestris*	roots	***
9	*Pholiota aurivella*	*Fagus sylvatica*	stem	**
10	*Fomes fomentarius*	*Fagus sylvatica, Quercus* spp.	stem	**
11	*Trametes versicolor*	*Fagus sylvatica*	stem	**
12	*Nectria* spp.	*Fagus sylvatica*	stem	**
13	*Pholiota adiposa*	*Carpinus betulus*	stem	**

Significance: *** – high; ** – medium: * – low

Wood-decay fungi of the *Pholiota* genus were detected on mature trees: *Pholiota aurivella* on *F. sylvatica* stems and *P. adiposa* on the single trees of common hornbeam (*Carpinus betulus* L.), growing in the same sample plot. The most serious damage responsible for single tree deterioration was necrosis caused by the pathogens of the *Nectria* genus. Necrosis was developed on branches and stems of infected trees.

On oak stems in sample plots in 'Nebesnite pasbishta' forest park, fruit bodies of *F. fomentarius* were detected. Bacterial cankers, caused by *Pseudomonas* sp. were noticed on oak stems. Symptoms included round-to-irregular sunken, swollen, cracked and dead areas on the stems.

Biotic factors – Insect pests

Eleven insect pests were found in the surveyed sites: seven on *Pinus sylvestris*, two on *Fagus sylvatica* and two on *Quercus cerris*, *Q. frainetto* and *Q. dalechampii* (Table 3). Six ones were xylophagous (affecting tree trunks) and the rest are phyllophagous, feeding on leaves and needles. With the exception of one species, *Corythucha arcuata* (Say, 1832) (Hemiptera: Tingidae), which is invasive, all other insect pests are native.

Two species are of high importance as pests (*Ips sexdentatus* and *Corythucha arcuata*) (Table 3). Three species (*Tomicus piniperda*, *Orchestes fagi* and *Dryomyia circinans*) and one group (*Pissodes* spp.) are of medium importance as pests, and the rest do not cause significant damage to the host plants.

Ips sexdentatus is one of the most dangerous bark beetles in pine plantations. The species usually develops on trees attacked by *Ips acuminatus*, which is the most aggressive xylophagous pest on *Pinus sylvestris*. At the time of the study, *I. acuminatus* was not found in the area, but it will undoubtedly appear in the near future, and will cause a dramatic drying of pine plantations.

The results from the investigation of the beech forest stand in the second sample plot near Etropole Monastery showed damage caused by insect pests *Orchestes fagi* and *Mikiola fagi* on leaves. The larvae of *O. fagi* mine the leaves, and the adults feed by mak-

Table 3. Insect pests causing damage of studied sample plots

N	Insect pests	Tree species	Affected parts	Origin	Significance
1	*Ips sexdentatus*	*Pinus sylvestris*	stem	native	***
2	*Pissodes* spp.	*Pinus sylvestris*	stem	native	**
3	*Tomicus piniperda*	*Pinus sylvestris*	stem	native	**
4	*Spondylitis buprestoides*	*Pinus sylvestris*	stem	native	*
5	*Asemum striatum*	*Pinus sylvestris*	stem	native	*
6	*Rhagium inquisitor*	*Pinus sylvestris*	stem	native	*
7	*Cinara pini*	Pinus sylvestris	needles	native	*
8	*Orchestes fagi*	*Fagus sylvatica*	leaves	native	**
9	*Mikiola fagi*	*Fagus sylvatica*	leaves	native	*
10	*Corythucha arcuata*	*Quercus cerris* *Quercus frainetto* *Quercus dalechampii*	leaves	alien	***
11	Dryomyia circinans	*Quercus cerris*	leaves	native	**

Significance: *** – high; ** – medium: * – low

Figure 6. Damage on *Quercus* spp. caused by *Corythucha arcuata*

ing holes in them. The species is found throughout the country and periodically causes damage in beech forests, which is easily compensated by the reserve capacity of host plants. As for *M. fagi*, the insect causes galls on leaves, but the damage is insignificant.

In the sample plot near Etropole Monastery, exit holes of xylophagous insects have been found on the trunks of felled beech trees. Many saproxylic insects develop in the dead and rotten wood, including species of high conservation importance – *Morimus asper funereus* Mulsant, 1862, *Rosalia alpina* (Linnaeus, 1758) (Coleoptera: Cerabycidae), etc.

Among the insect pests, *Corythucha arcuata* (Heteroptera: Tingidae) and *Dryomyia circinans* (Giraud, 1861) (Diptera: Cecidomyiidae) were the most numerous in the oak coppice stand in 'Nebesnite pasbishta' forest park near Osikovitsa village. *D. circinans* caused strong damage on the studied *Quercus cerris* sample trees. The leaves were completely coved by galls, worsening the aesthetic qualities of the infested trees and causing decrease of growth and physiological weakness. In this study, *C. arcuata* was established mainly on *Quercus cerris* and *Q. frainetto*, and rarely on *Q. dalechampii* (Fig. 6). It was found as larvae, nymphae and adults on the host plants. Finding a single adult on *Carpinus betulus* leaves could be considered as rare records.

The invasive species *C. arcuata* is a serious threat to oak forests and should therefore be subject to permanent monitoring in the studied area. This is even more true for the most dangerous insect pest in deciduous forests, the gypsy moth (*Lymantria dispar*), which forms calamities every 8-10 years. Monitoring with pheromone traps would allow early biological control to be applied using the specific and highly effective fungal pathogen *Entomophaga maimaiga*.

Discussion

The study provides information for early detection and identification of pests and pathogens causing damage in different forest types in the region of Etropole and

Pravets municipalities. In the urban area of Etropole municipalities, the ecological problems were particularly manifested in Scots pine plantations. Some of them were planted for the restoration of degraded lands, in atypical habitats at lower altitudes where early pine mortality was registered (Popov et al., 2015, 2016). A process of incremented damage by biotic and abiotic factors contributes significantly to the rapid destruction of pine plantations.

Both emerging and identified pests and diseases in the urban areas of Etropole are important for the aesthetic vision of the forests, and for the good health and social status of residents and visitors. Damage by the invasive pathogen *Dothistroma septosporum* on the needles of *Pinus sylvestris* trees showed strong virulence. In recent years, the pathogens *D. septosporum* and *Lecanosticta acicola* have caused serious damage to local and introduced coniferous tree species in the country (Georgieva, 2020).

Among xylophages, the most dangerous and economically harmful for pine trees are bark beetles in the *Ips* genus (Mirchev et al., 2016). At the time of the study, *Ips sexdentatus* was identified in the most deteriorated pine trees. *I. acuminatus* was not found in the area, but it will undoubtedly appear in the near future, and will cause a dramatic drying of pine plantations.

During the field inspections, attacks of several dangerous pests were found in deciduous forests. In oak sample plots, severe damage was caused by the invasive species *Corythucha arcuata*.

Using NDVI in monitoring and assessment of the health status of vegetation in different types of ecosystems aims to improve the understanding, predictions, and impacts of disturbances such as drought, fire, flood, pests and diseases on global vegetation resources (Pettorelli et al., 2014). In the present study, NDVI was calculated for two areas captured by UAV – a Scots pine plantation near the town of Etropole and an oak coppice stand near Osikovitsa village. It was established that the pine plantations were in bad health status, with NDVI values most often between 0.47 and 0.66. The oak stands were in better health condition (NDVI was between 0.79-0.98).

In conclusion, it could be noted that the severe attacks by invasive pathogens and pests violate the ecological role of forests, as well as their economic function and recreational purpose. The monitoring of the health status of urban forests based on remote sensing data and field investigations could provide very useful information for early detection and identification of penetrated pests and pathogens, which is of importance for the development of measures to limit their negative impact.

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