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RESEARCH ARTICLE

Early detection of *Ips typographus* infestations by using Sentinel-2 satellite images in windthrow affected Norway spruce forests in Smolyan region, Bulgaria

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Abstract

Strong winds uprooted more than 100 thousand m^3 of coniferous trees in natural forest stands nearby the town of Smolyan (the Western Rhodopes) in January 2018. Although damaged trees were quickly removed from the stands, the European spruce bark beetle (*Ips typographus*) attacked the healthy Norway spruce trees near the windthrow areas in August 2020. Our hypothesis was that the trees were infested by the pest in previous years when no symptoms of attacks were observed. This study was conducted in three spruce stands, located near the windthrow areas and attacked by *I. typographus*, and in three control (healthy) stands located 5-10 km from the affected areas. We used satellite images captured by Sentinel-2 in September 2017-2020. It was established that in September 2017 (a year before the windthrow), the mean values of the Normalized difference vegetation index (NDVI) in the attacked stands were concentrated between 0.60 and 0.75 (with a maximum at 0.70), indicating that the trees were in good health. During the period 2018-2020 the distribution of mean values of NDVI was stretched between 0.35 and 0.75, which is an indication of evidence of pest attacks on the individual trees. The detail comparison of pixel values of the NDVI in the attacked and control sample plots was made on the base of images captured on 27.06.2020. The mean NDVI values in the three control plots (0.74-0.79) were much higher than the mean values in the sample plots attacked by the pest (0.57-0.65). These results showed that the values of NDVI based on satellite remote sensing data of Sentinel-2 can be used for early detection of *I. typographus* infestations in spruce stands around the windthrows. These data are important for rapid planning and implementing the sanitary feelings that reduce the pest population.

Keywords
Ips typographus, spruce forests, windthrow damages, satellite images, NDVI, Western Rhodopes, Bulgaria

Introduction

The State Forestry Smolyan is located in the Western Rhodopes at a territory of 28368.3 ha with mountainous landscape, different climatic characteristics and plant species biodiversity. Coniferous stands occupy 75.4% of the forested area with main tree species Norway spruce (*Picea abies* (L.) Karst.) – 35%, Scots pine (*Pinus sylvestris* L.) – 27%, Austrian pine (*Pinus nigra* Arnold) – 8%, and European silver fir (*Abies alba* Mill.) – 5%.

Natural disturbances caused by abiotic factors periodically occur in mountain forest ecosystems. Severe damages from wet snow were recorded in Scots pine plantations in the region of Smolyan in 2015. In 2018 strong winds brought down more than 100 thousand m^3 of coniferous trees in natural forest stands nearby the town (Belilov et al., 2022). The damaged trees were removed in less than one year from the affected stands. Nevertheless, the presence of fresh food substrate (stumps and stem residues) contributed to the multiplication of the European spruce bark beetle (*Ips typographus* Linnaeus, 1758) (Coleoptera: Curculionidae, Scolytinae) attacking healthy Norway spruce trees near the windthrow area. The first visible symptoms of the pest infestations were observed in 2020.

The application of remote sensing data based on images captured by satellites or unmanned aerial vehicles (UAV) has consistently increased for assessment the health status of forest ecosystems. Despite the appearance of new equipment and methods, satellite-borne multispectral sensors are the most commonly used technology for monitoring and assessment of the forest health condition (Torres et al., 2021). An integrated approach including the use of RGB orthophotos, multispectral data and terrestrial verification has been successfully applied in Bulgaria for mapping the bark beetle spots of *Ips typographus* (Dimitrov et al., 2019; Georgiev et al., 2022) and of *Ips acuminatus* (Gyllenhal, 1827) (Georgieva et al., 2022).

The aim of this study was to investigate the possibility of using the satellite images for early detection of *Ips typographus* infestations in Norway spruce stands around the windthrow areas in Smolyan region.

Material and Methods

The study was conducted in three spruce stands infested by *Ips typographus* near the windthrow areas (SP), and in three control (healthy) stands (CP) with similar structural characteristics, located 5-10 km from the damaged areas. The main characteristics of the sample plots are shown in Table 1.

Table 1. Main characteristics of the studied Norway spruce stands

N	Forest unit	Geographical coordinates	Altitude, m	Forest species* (Relative share, %)	Age, years
		Control (healthy) plots			
CP 1	98-f	41.599969°N, 24.694839°E	1420	Pa (90%), Ps (10%)	110
CP 2	2038-c	41.680688°N, 24.775218°E	1380	Pa (70%), Ps (10%), Aa (20%)	100
CP 3	3136-b	41.653501°N, 24.750588°E	1160	Pa (80%), Pn (20%)	100
		Attacked sample plots			
SP 1	163-g	41.559110°N, 24.704345°E	1220	Ps (40%), Pa (60%)	90
SP 2	165-x	41.558201°N, 24.691020°E	1330	Pa (60%), Ps (30%), Aa (10%)	90
SP 3	194-f	41.544936°N, 24.619699°E	1460	Pa (80%), Ps (20%)	100

* Aa – *Abies alba*; Pa – *Picea abies*; Pn – *Pinus nigra*; Ps – *Pinus sylvestris*

Satellite images captured by Sentinel-2 of the European Space Agency in September 2017-2020 were used to assess the earliest infestation of the pest in the studied spruce stands. Sentinel-2 has a multispectral instrument of a passive type, recording sunlight reflected from the Earth's surface with a spatial resolution of 10 m for visible and near-infrared bands, and 20 m and 60 m for short wave infrared bands. Imaging is performed in 13 spectral bands in the visible and near-infrared part of the electromagnetic spectrum (VNIR from 400 to 1100 nm) and short-wave infrared part (SWIR from 1100 to 3000 nm). The recording frequency is 5 days for the equator and 3 days for the other latitudes. The data is freely accessible. The images were acquired using the application Earth Explorer of US Geological Survey. Raster image processing was performed with QGIS-3 – a professional open source GIS application.

Pre-processing of the used images was carried out in order to remove the influence of water vapor and other particles located in the atmospheric layers above the studied objects. Shape files of the surveyed spruce stands were created.

Based on the spectral characteristics of the registered multispectral images, the Normalized difference vegetation index (NDVI) was calculated, which is the main indicator of the health status and vitality of the vegetation. NDVI is a mathematical combination between the red band (B4) and the nearinfrared (NIR) band (B8) that produces values between -1 to +1, according to the following expression:

$$NDVI = \frac{B8-B4}{B8+B4}$$

where B_8 is a spectral band of Sentinel-2 with a wavelength of 665 nm; B_4 – with a wavelength of 842 nm.

The comparison of pixel values of NDVI in the attacked and control plots was made by satellite images captured on 27.06.2020. Extraction of the investigated raster images was performed with subsequent raster analysis of all pixel values in each raster layer.

Statistical evaluation of NDVI values was performed using descriptive statistics of Statistica 12.0 for

Windows (StatSoft). The results were cited together with their standard error. T-test for independent samples was applied to compare the means.

The terrain verification of *Ips typographus* attacks was performed in the sample plots on 06.08.2020.

Results

The first visible infestations by *Ips typographus* in the healthy Norway spruce stands near the windthrow sites were observed in late July – early August 2020. The main symptoms of the pest development were observed: discoloration of tree crowns (Fig. 1A) and the preliminary fall of needles on the ground. The development of *I. typographus's* second generation under the bark of stems was also established (Fig. 1B).

The presence of *I. typographus* infestations in the spruce stands adjacent to the windthrow in August 2020 was a reason to hypothesize that the same trees were infested by the pest in previous years, when no symptoms of attacks were observed.

In September 2017 (before the windthrow), the mean values of NDVI in attacked stands were concentrated between 0.60 and 0.75 (with a maximum of 0.70), indicating good vitality of spruce stands (Fig. 2). In next years (September, 2018-2020), the main distribution of mean values of NDVI was between 0.35 and 0.75), which is an indication of pest attacks on individual trees.

The NDVI models of the studied areas on the base of satellite images captured on 27.06.2020 (before the appearance of visible symptoms of *I. typographus* attack) showed that in the control plots that were away from the windthrow the spruce stands were in good health status (Fig. 3 A-C), in contrast to the sample plots close to the damaged areas (Fig. 3 D-F).

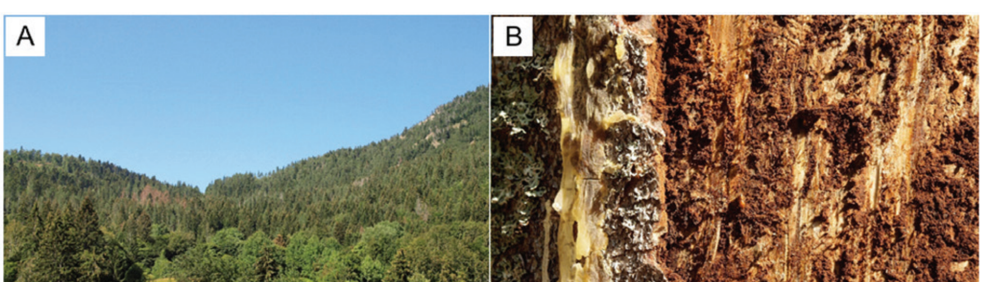

Figure 1. *Ips typographus* attacks (06.08.2020): A – attacked spruce stands; B – galleries and emerged adults of *Ips typographus* under the bark of attacked tree

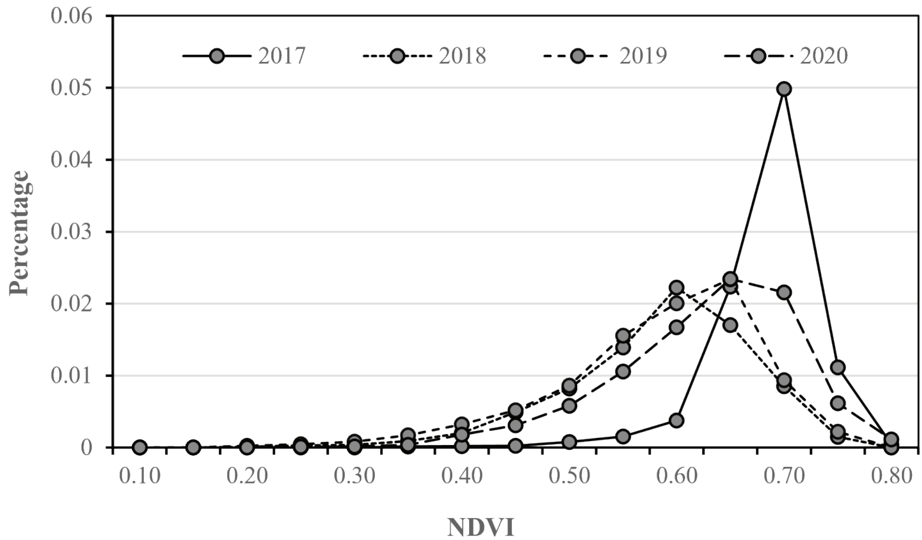

Figure 2. Distribution of mean NDVI values in three attacked spruce stands in the period 2017-2020

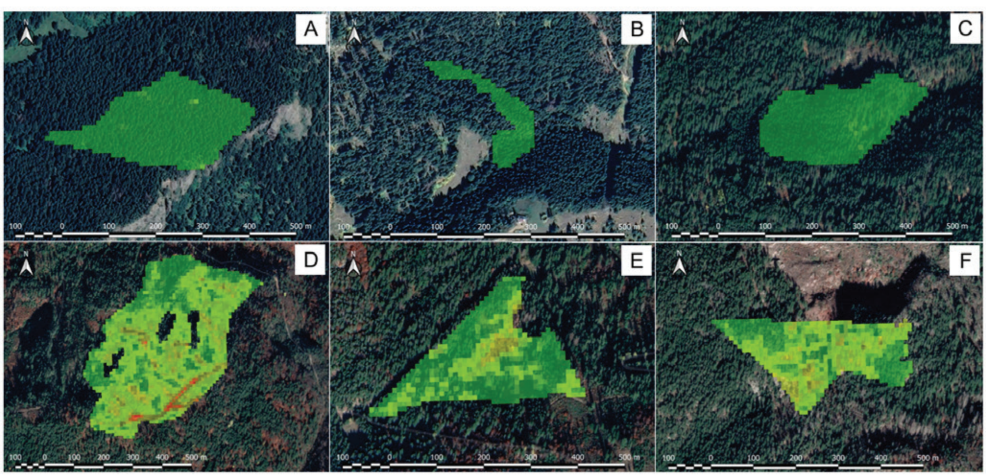

Figure 3. NDVI models of studied areas (27.06.2020): A – Control plot 1 (98-f); B – Control plot 2 (2038-c); C – Control plot 3 (3136-b); D – Sample plot 1 (163-g); E – Sample plot 2 (165-x); F – Sample plot 3 (194-f)

The mean NDVI values in the three control plots (CP1=0.74±0.02; CP2 and CP3=0.79±0.03) were much higher than the mean values in the sample plots with pest attacks (SP1=0.57±0.09; SP2=0.65±0.05; SP3=0.59±0.05) (Fig. 4).

The differences in the mean NDVI values from three control plots without *I. typographus* attacks (CP1 – CP3) and the sample plots attacked by the pest (SP1 – SP3) were statistically proven ($p<0.001$).

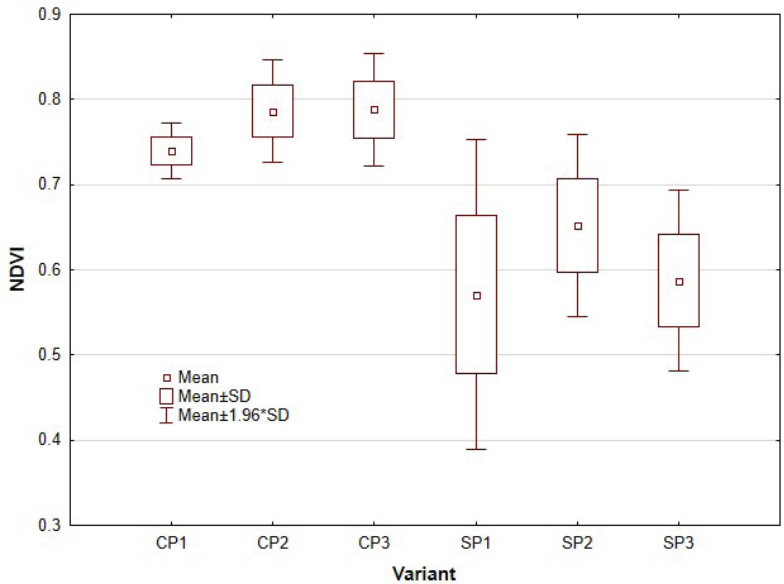

Figure 4. Pixel values of NDVI in the captured areas (27.06.2020): A – Control plot 1 (98-f); B – Control plot 2 (2038-c); C – Control plot 3 (3136-b); D – Sample plot 1 (163-g); E – Sample plot 2 (165-x); F – Sample plot 3 (194-f)

Discussion

Ips typographus is one of the most destructive xylophagous insect pests of Norway spruce species in Europe (Kaminska et al., 2021). Its outbreaks are usually caused by disturbances or extreme weather conditions (Wermelinger, 2004). Several outbreaks of the pest were recorded in the 20th century in various parts of Europe where over 100 million m^3 of spruce trees were killed (CAB International, 2021).

In Bulgaria, *I. typographus* does not usually cause strong damage to the managed spruce forests because of the intensive sanitary and control measures. Conversely, in protected areas, the pest develops on fallen and broken fresh trees, increases in number and attacks healthy stands. In 2001, a tornado affected mature spruce stands on 62 ha in Bistrishko Branishte Biosphere Reserve in Vitosha Mountain, after which *I. typographus* population first developed in windthrown timber, and from 2003 to 2005, spruce trees on over 200 ha were killed by the pest near the windthrow in the reserve (Rossnev et al., 2005).

In the Smolyan region, it was found that the use of NDVI from multispectral UAV and satellite data is not suitable for long-term monitoring of windfall forest areas due to the overgrowth of damaged stands with grass and shrub vegetation (Belilov et al., 2022).

It is well known that the symptoms of the advanced stages of bark beetle infestation (i.e. red attack), can be observed using the visible part of the electromagnetic spectrum (400 to 700 nm), but the detection of early stage symptoms (i.e. green attack) is more effective using sensors in near-infrared (700 to 1300 nm) and shortwave infrared (1300 to 2500 nm) spectrum (Abdullah, 2019).

In the Polish part of the Białowieża Forest, *I. typographus* outbreak was estimated by mapping dead spruce stands on a tree level using airborne hyperspectral and laser scanning data obtained from HySpex VNIR-1800 camera and Riegl LMS-Q680i scanner (Sterenczak et al., 2019, 2020). Satellite optical and thermal data of Landsat-8 and Sentinel-2 were successfully used to investigate the early stage of *I. typographus* infestation in the Bavarian Forest National Park in Germany (Abdullah et al., 2018, 2019). The authors established that the majority of spectral vegetation indices calculated from Sentinel-2, particularly red-edge dependent indices (NDRE 2 and 3) and water-related indices (SR-SWIR, NDWI, DSWI and LWCI) are able to discriminate healthy from infested plots. In addition, satellite images of WorldView-2, Pléiades 1B, and SPOT-6 were also used for detection of early stage of pest infestation in the Czech Republic (Abdollahnejad et al., 2021). The authors determined that identifying physiological stress in earlier stages could be more feasible, with higher reliability and accuracy, using hyperspectral sensors in wavelengths that multispectral sensors cannot cover.

Multispectral UAV-based imagery is capable of classifying tree decline during a bark beetle infestations in Scots pine (Georgieva et al., 2022) and Norway spruce (Junttila et al., 2022). Recent studies of spruce bark beetle attacks using Sentinel-2 multispectral data and different vegetation indices (including NDVI) in the Italian Alps show that the two stages of the epidemic (i.e. early and late) can be detected with an overall accuracy of 83.4% (Dalponte et al., 2022).

In conclusion, the present study showed that periodic observations and analyzes based on NDVI from satellite data of Sentinel-2 can serve reliably for early detection of *I. typographus* infestations in spruce stands around windbreak and windfalls in mountain areas. From a management point of view, the possibility to detect the attack of the European spruce bark beetle at an early stage using freely available satellite data is very important for rapid planning and implementing of sanitary measures in order to reduce the pest attacks.

Acknowledgments

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Reference

Abdollahnejad A., Panagiotidis D., Surový P., Modlinger R. 2021. Investigating the Correlation between Multisource Remote Sensing Data for Predicting Potential Spread of *Ips typographus* L. Spots in Healthy Trees. Remote Sensing 13, 4953. https://doi.org/10.3390/rs13234953

Abdullah H.J. 2019. Remote sensing of European spruce (*Ips typographus*, L.) bark beetle green attack. Dissertation to obtain the degree of doctor at the University of Twente. The Netherlands 151 pp. DOI 10.3990/1.9789036547956

Abdullah H., SkidmoreA.K. , DarvishzadehR., Heurich M. 2018. Sentinel-2 accurately maps green-attack stage of European spruce bark beetle (*Ips typographus* L.) compared with Landsat-8. Remote Sensing in Ecology and Conservation 1-20. doi: 10.1002/rse2.93

Abdullah H., Darvishzadeh R., Skidmore A.K., Heurich M. 2019. Sensitivity of Landsat-8 OLI and TIRS Data to Foliar Properties of Early Stage Bark Beetle (*Ips typographus* L.) Infestation. Remote Sensing 11, 398. https://doi:10.3390/rs11040398

Belilov S., Georgiev G., Georgieva M., Mirchev P., Kechev M., Zaemdzhikova G., Matova M., Petrova V.,. Hristova M, Katinova B., Madzhov S., Georgieva L. 2022. Bark beetle attacks in abiotic impacted coniferous forests in Smolyan region and monitoring of the damages by remote sensing methods. Forest Science, Special Issue II, 103-110.

CAB International. 2021. *Ips typographus* (Linnaeus, 1758). In: Crop Protection Compendium. Wallingford, UK: CAB International. https://www.cabi.org/isc/datasheet/28843

Dalponte M., Solano-Correa Y.T., Frizzera L., Gianelle D. 2022. Mapping a European Spruce Bark Beetle Outbreak Using Sentinel-2 Remote Sensing Data. Remote Sensing 14, 3135. https://doi.org/10.3390/rs14133135

Dimitrov S., Georgiev G., Mirchev P., Georgieva M., Iliev M., Doychev D., Bencheva S., Zaemdzhikova G., Zaphirov N. 2019. Integrated model of application of remote sensing and field investigations for sanitary status assessment of forest stands in two reserves in West Balkan Range, Bulgaria. Proceedings of SPIE, 11174, Seventh International Conference on Remote Sensing and Geoinformation of the Environment (RSCy2019), Paphos, Cyprus, 1117404. doi: 10.1117/12.2532313

Georgiev G., Georgieva M., Dimitrov S., Iliev M., Trenkin V., Mirchev P., Belilov S. 2022. Remote Sensing Assessment of the Expansion of *Ips typographus* Attacks in the Chuprene Reserve, Western Balkan Range. Forests 13, 39. https://doi.org/10.3390/f13010039

Georgieva M., Belilov S., Dimitrov S., Iliev M., Trenkin V., Mirchev P., Georgiev G.. 2022. Application of Remote Sensing Data for Assessment of Bark Beetle Attacks in Pine Plantations in Kirkovo Region, the Eastern Rhodopes. Forests 13, 620. https://doi.org/10.3390/f13040620

Junttila S., Näsi R., Koivumäki N., Imangholiloo M., Saarinen N., Raisio J., Holopainen M., Hyyppä H., Hyyppä J., Lyytikäinen-Saarenmaa P., Vastaranta M., Honkavaara E. 2022. Multispectral Imagery Provides Benefits for Mapping Spruce Tree Decline Due to Bark Beetle Infestation When Acquired Late in the Season. Remote Sensing 14, 909. https://doi.org/10.3390/rs14040909

Kaminska A., Lisiewicz M., Kraszewski B., Sterenczak K. 2021. Mass outbreaks and factors related to the spatial dynamics of spruce bark beetle (*Ips typographus*) dieback considering diverse management regimes in the Białowieża forest. Forest Ecology and Management 498, 119530. https://doi.org/10.1016/j.foreco.2021.119530

Rossnev B., Georgiev G., Mirchev P., Tsankov G., Petkov P. 2005. Influence of the wind throw in Biosphere reserve Bistrishko Branishte on the number of *Ips typographus* (L.) (Coleoptera: Scolytidae) and the condition of *Picea abies* L. (Karst.) plantations on Vitosha. Agricultural University – Plovdiv, Scientific Works 50 (6), 239-244. (In Bulgarian, English summary).

Sterenczak K., Mielcarek M., Modzelewska A., Kraszewski B., Fassnacht F.E., Hilszczanski J. 2019. Intra-annual *Ips typographus* outbreak monitoring using a multi-temporal GIS analysis based on hyperspectral and ALS data in the Białowieża Forests. Forest Ecology and Management 442, 105-116.

Sterenczak K., Mielcarek M., Kaminska A., Kraszewski B., Piasecka Z., Miścicki S., Heurich M. 2020. Influence of selected habitat and stand factors on bark beetle *Ips typographus* (L.) outbreak in the Białowieża Forest. Forest Ecology and Management 459, 117826.

Torres P., Rodes-Blanco M., Viana-Soto A., Nieto H., García M. 2021. The Role of Remote Sensing for the Assessment and Monitoring of Forest Health: A Systematic Evidence Synthesis. Forests 12, 1134.

Wermelinger B. 2004. Ecology and management of the spruce bark beetle *Ips typographus* – a review of recent research. Forest Ecology and Management 202, 67-82.