DOI: 10.21120/LE/17/1/3 **Landscape & Environment 17 (1) 2023. 33-40**

SENTINEL-2 SATELLITE-BASED ANALYSIS OF BARK BEETLE DAMAGE IN SOPRON MOUNTAINS, HUNGARY

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Received 10 May 2023, accepted in revised form 30 May 2023

Abstract
Sopron mountains were affected by bark beetle (Ips typographus) damage between 2017 and 2020, which was surveyed on high-resolution ESA Sentinel-2 satellite images for the period 2017 and 2020 using Mosaic Hub, Anaconda, and Jupyter Notebook web-based computing environments. Biotic forest damage was detected based on vegetation (NDVI) and moisture (MSI, NDWI) indices derived from satellite images. The spatial and temporal change of damage was observed in the image series, resulting in information about the level of degradation and regeneration. In pursuance of GIS processing, 84 forest compartments were compared, which showed in most of the cases (97%) negative interannual change in the index mean values (MSI = - 0.14, NDWI = - 0.2, NDVI= - 0.19) when years compared to each other. The remote sensing-based survey was marked out and validated based on the forest database of the Hungarian Division of Forest of National Land Centre and forest protection damage reports of the Hungarian National Forest Damage Registration System.

Keywords: forest monitoring, remote-sensing, satellite image, bark beetle damage, Sentinel-2, vegetation index, water index

1. Introduction

European spruce bark beetle (Ips typographus) caused severe damage in the last decades in Sopron Mountains, Western Hungary. Dry periods could effort local outbreaks of biotic agents like bark beetle (Roth 2003). Since the early 90s, the devastation is even more severe due to climate change, resulting in the area of monoculture spruce forest in Sopron decreasing from 1000 ha to 200 ha and still decreasing (Csóka et al. 2018). In 2017- 2020 another wave occurred and in total 450 hectares of spruce-dominated forest were affected according to the forest protection damage reports of the Hungarian National Forest Damage Registration System (OENyR) (Hirka 2019, 2020). In addition, European Larch (Larix decidua) was also reported as a new host to spruce bark beetles, while six-toothed bark beetle (Ips sexdentatus) appeared as well on Scots pine (Pinus sylvestris) and Black pine (Pinus nigra). The spread of both beetle species to new hosts is expected.

The bark beetle causes problems in many European countries and remote sensing was used to detect them. In Czechia Barka et al. (2018), Fernandez-Carrillo et al. (2020), and Bárta et al. (2021) used Sentinel-2 image series to detect health decline and effects of bark beetle attacks. In Finland, Honkavaara et al. (2020) used multitemporal hyper- and multispectral UAV images fused with an air-borne laser-scanned 3D point cloud. Their work included individual tree detection, feature extraction, tree species classification, and finally tree health classification. 40-55 % overall accuracy was reported by them.

The study area was selected based on these reports and studied by Remote Sensing (RS) methods and the goal of the study was to monitor the changes from the initial stage of beetle attack to the ultimate sanitary logging. Another aspect of the study is the comparison of ground-based and space-based damage surveys. For the latter, we used the high-resolution Sentinel-2 satellite image mosaics of the European Space Agency (ESA).

2. Materials and methods

Ground-based dataset

The damage to the spruce bark beetle was registered in the forest protection damage reports of the Hungarian National Forest Damage Registration System of the Hungarian National Land Center. The data contains information about damage frequency and intensity which is given for each forest compartment expressed in the percentage of damaged trees for each tree species (0-100%), and the intensity of damage (0-100%) respectively (Hirka 2019). From the database 84 forest compartment (Figure 1) were selected with 100% frequency and intensity. In addition, damage ratio (1) was calculated from the damaged area registered in inventory and the total forest compartment area:

$$Damage\ ratio = \frac{Damaged\ area}{Total\ area} * 100 \quad (1)$$

This calculation was important since if 100% damage frequency and intensity were registered in a forest compartment means in theory that the damage is the most severe, and no healthy trees are remaining. But in practice, only part of the compartment is surveyed in the field of which size is registered also in ha. The calculations showed that the mean damage ratio of the 84 compartments is only 11,55 %, which had great importance when compared to the RS data and it was explained in the results.

Satellite-based dataset

ESA Sentinel-2 MSI satellite image mosaics give the basis for remote-sensing damage survey at 10x10 m spatial resolution. The annual composites were ordered from The Sentinel-2 Global Mosaic Service or shortly Mosaic Hub which provided time-series composites of Sentinel-2 surface reflectance images, based on the best available pixels. From the composite's state and change, indices were derived. The state index refers to the actual state of the forests in the given year (2017, 2018, 2019, 2020) and the change index shows the difference between the years (2017-2018, 2018-2019, 2019-2020, 2020-2021).

The Normalized Difference Vegetation Index (NDVI) (2) is one of the most used indexes for the photosynthetic activity of vegetation and can be calculated according to this formula:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (2)$$

Red is band 4 and NIR (near-infrared) is band 8 in the case of Sentinel-2. High NDVI values refer to high photosynthetic activity and healthy vegetation and high vegetation cover while low index values to unhealthy vegetation and less vegetation cover. The range of NDVI is between -1 (water surface) and +1 (healthy vegetation). Typically, a healthy forest reaches 0.8-0.9 depending on tree species and vegetation period.

The Normalized Difference Water Index

(NDWI) (3) is a widely used index for the water content of vegetation and can be calculated according to this formula:

$$NDWI = \frac{NIR-SWIR}{NIR+SWIR} \quad (3)$$

NIR (near-infrared) is band 8 and SWIR (short-wave infrared) is band 11 in the case of Sentinel-2. High NDWI values correspond to high vegetation water content and cover while low index values to low vegetation water content and cover. During the period of water stress or after logging NDWI decreases. The range of NDWI is like NDVI, where -1 refers to the driest and +1 to the wettest state.

The Moisture Stress Index (MSI) (4) refer to the moisture content of the vegetation similar to NDWI but here the higher values indicate higher water stress and less water content, and the values of this index range from 0 to more than 3, while green vegetation is between 0.4 and 2.

$$MSI = \frac{NIR}{SWIR} \quad (4)$$

The change indices (5) are calculated from all three indices (NDVI, NDWI, MSI) y subtraction of the given year's value (actual) from the previous year's value (previous).

$$NVDI_{change} = \mathrm{NDVI}_{\mathrm{actual}} - \mathrm{NDVI}_{\mathrm{previous}} \quad (5)$$

NDWI and MSI changes were calculated similarly to NDVI change, the range is from -1 to +1 or -2 - +2 respectively.

Processing environment

The image processing was made in Anaconda (2020) and Jupyter Notebook (2016) environments. The Anaconda is Python and R language-based platform for data science and open-source machine learning while Jupyter Notebook is a web application for creating and sharing codes, equations, data visualizations, and machine learning, built in the Anaconda as a package.

Sentinel-2 mosaics were created by Mosaic Hub and imported to Jupyter Notebook as input and the maps created online there were exported to the PC's hard disk, where QGIS 3.20. (QGIS, 2021) open-source cross-platform desktop geographic information system (GIS) was used for further processing. The raster maps were imported into QGIS, also the forest compartment polygons. For the latter, zonal statistics were calculated based on the majority. The majority was selected to show the difference between the most important i.e., the most damaged parts of the compartments when mean or median values would likely take away these differences. We calculated mean values across all forest compartments from the majority values of NDVI, NDWI, and MSI.

3. Results and discussion

The biotic damage was detected by both methods, the field survey of the forest protection damage reports showed the ratio of damaged forest area within each forest compartment while the vegetation (NDVI) and water change indices (NDWI, MSI) derived from satellite images showed a decrease of index values, corresponding to the damage.

The mean of change index majority values was calculated for all 84 forest compartments and 96,96% of them showed degradation (Table 1.). There are differences between the years, but generally visible that NDVI and NDWI values decreased more and more from 2017 to 2020, with mean, annual change values decreasing from -0,12 in 2017-18 to -0,29 in 2019-2020 (for NDVI). MSI showed degradation (negative values) as well but of smaller magnitude due to the different scale. The mean change across all years of NDVI values was -0.19, while -0.2 for NDWI and -0,14 for MSI, which all refer to significant changes. It is also visible that the degradation is gradual, in the initial stage in 2018 (Figure 2) the NDVI change was -0.13, while in 2019 (Figure 3) it was 0.19 in the state of more severe damage, while in 2020 (Figure 4) it was -0.27 which is the lowest value, which could also refer to sanitary logging.

Table 1. Mean values of Change index values of forest compartments

	NDVI change 2018	NDVI change 2019	NDVI change 2020	NDWI change 2018	NDWI change 2019	NDWI change 2020	MSI change 2018	MSI change 2019	MSI change 2020
Index mean	-0.13	-0.19	-0.27	-0.12	-0.19	-0.29	-0.15	-0.10	-0.16
Regeneration (pc)	2	4	3	3	2	1	2	3	3
Degradation (pc)	82	80	81	81	82	83	82	81	81
Degradation ratio (%)	97.62	95.24	96.43	96.43	97.62	98.81	97.62	96.43	96.43

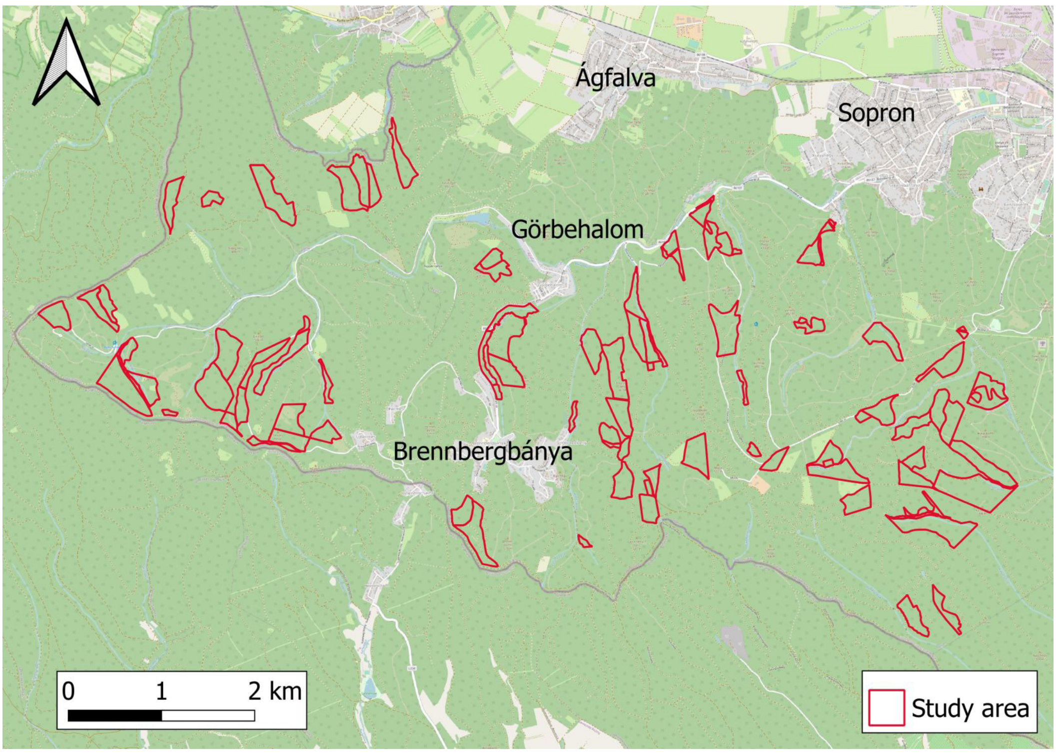

Fig. 1. The location of the study area in Sopron Mountains, Western Hungary

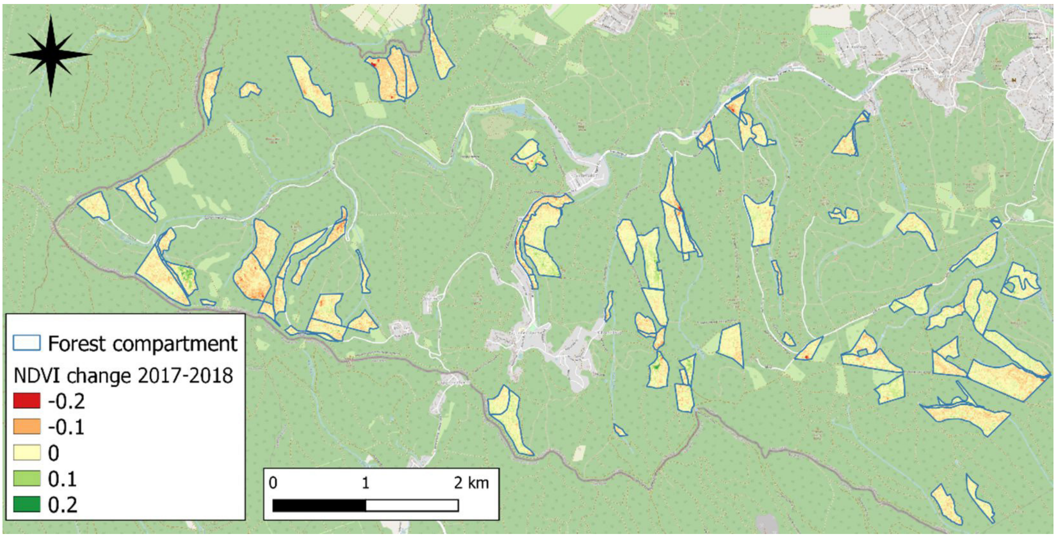

Fig. 2. NDVI change map of 2017 and 2018 of Sopron Mountains. The first stage of bark beetle gradation is marked by orange and red patches representing negative NDVI change values

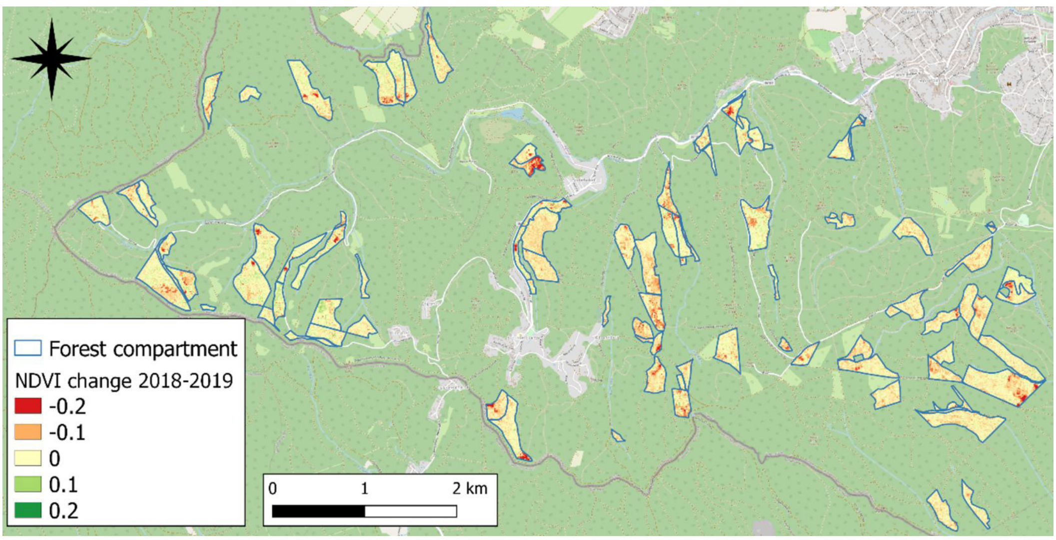

Fig. 3 NDVI change map of 2018 and 2019 of Sopron Mountains. The second stage of bark beetle gradation is marked by orange and red patches representing further degradation

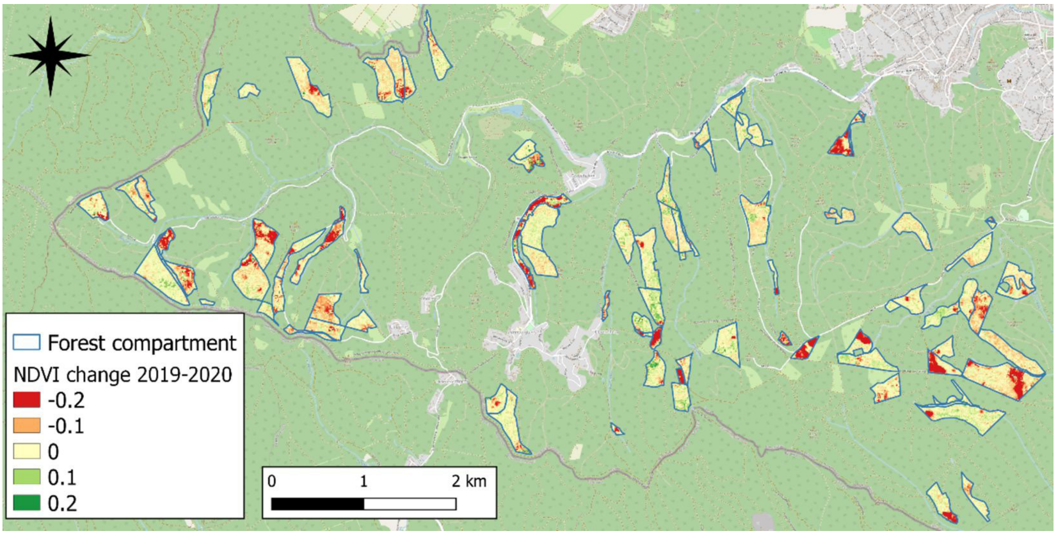

Fig. 4. NDVI change map of 2019 and 2020 of Sopron Mountains. The final stage of bark beetle gradation is marked by mostly red patches representing sanitary logging

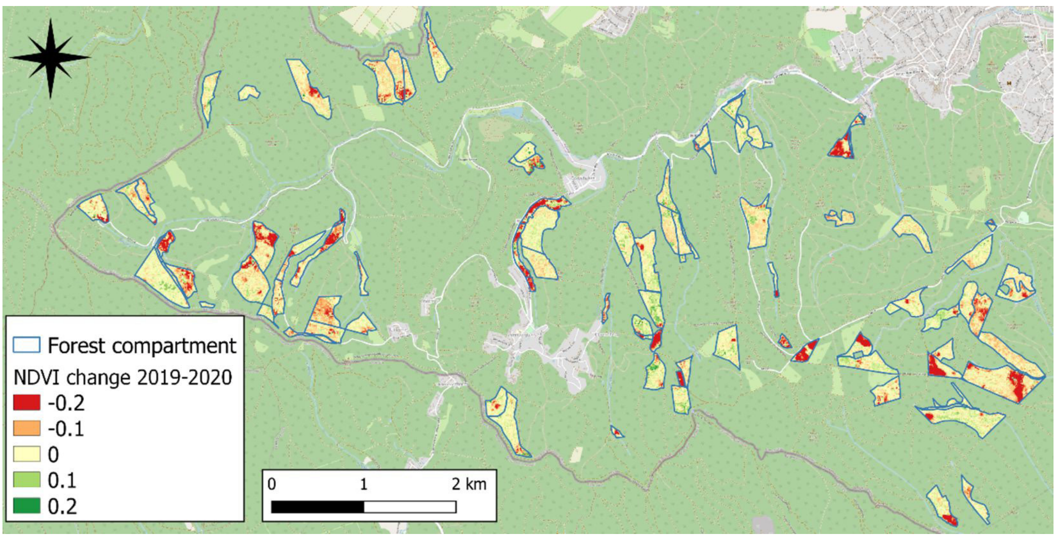

Fig. 5. NDWI change map between 2019 and 2020 of Sopron Mountains. The different size of more and less affected areas is visible in each forest compartment

The mean values of the ground-based damage ratio (11,55%) seem to be too low compared to the mean value of satellite-based damage (96,96%), which was explained by the ground sampling methods already but draws attention to the fact that field reports cannot be accepted as ground truth in every case. This does not mean that they are incorrect but states the importance of developing new methods which could be more precisely compared to each other. While the Sentinel-2 images have 100 m2 resolution, the field surveys were made for mean 5.3 ha large compartments in this case, which is a large difference (Figure 5). In addition, RS shows the exact location of the forest damages inside the compartment unlike the field reports, where it is not registered, only the damage frequency and intensity.

Another possible application of this method could be the expansion of the survey for the whole of Hungary to check biotic damages caused by a relatively new invasive species called the oak lace bug (Corythucha arcuata). According to Paulin et al (2020), this new biotic agent is present all around the country posing multiple threats to oak ecosystems, which means one-third of Hungarian forests. The problem is even more severe south of Hungary and in Croatia for example and RS was successfully applied to investigate the impacts in both countries by Kern et al (2021).

Acknowledgements

We wish to thank the Division of Forest of National Land Centre of Hungary for providing data from Forest Database and Forest Protection Damage Reports of the Hungarian National Forest Damage Registration System. We also thank Dr Svein Solberg from the Norwegian Institute of Bioeconomy Research (NIBIO) for providing the knowledge and infrastructure and the Tempus Public Foundation of Hungary for supporting the travels to Norway. Special thanks to Dr Zoltán Somogyi (Hungarian Forest Research Institute) and Dr Szilárd Szabó (University of Debrecen) for comments and advice on the manuscript.

This article was made in the frame of the project TKP2021-NKTA-43 which has been implemented with the support provided by the Ministry of Innovation and Technology of Hungary (successor: Ministry of Culture and Innovation of Hungary) from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme.

The article was funded by EFOP-3.4.3-16-2016-00022 „QUALITY Qualitative higher education development in Sopron, Szombathely and Tata" project at University of Sopron, Hungary.

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