COMPARING SPECTRAL DIFFERENCES BETWEEN HEALTHY AND EARLY INFESTED SPRUCE PLOTS CAUSED BY BARK BEETLE ATTACKS USING SATELLITE IMAGES

Langning Huo[1], Eva Lindberg[1], Johan E.S. Fransson[2], Henrik Jan Persson[1]

[1] Swedish University of Agricultural Sciences, Department of Forest Resource Management, SE-901 83 Umeå, Sweden

[2] Linnaeus University, Department of Forestry and Wood Technology, SE-351 95 Växjö, Sweden

ABSTRACT

Detecting forest insect damages before the visible discoloration (green attacks) using remote sensing data is challenging but important for damage control. In recent years, the European spruce bark beetle (*Ips typographus*, L.) has damaged large amounts of forest in Europe. However, it is still debatable how early the infestations can be detected with remote sensing data. Some studies showed a spectral difference between healthy and green-attacked spruce plots, while others showed that spectral differences existed before attacks. Therefore, a hypothesis is proposed that no spectral difference can be identified in green attacked plots compared to healthy forests if the differences do not exist before the attacks. In this study, we tested this hypothesis using Sentinel-2 and WorldView-3 SWIR images. We used 24 experimental field plots and 24 control plots. All of them were healthy in the spring of 2021. We put pheromone bags in the experimental plots to attract bark beetles, resulting in severe, moderate, and mild infestations. No treatment was conducted in the control plots, and no infestation was found from spring to autumn 2021. Eight Sentinel-2 images were obtained from spring to autumn, and one WorldView-3 image was obtained in June. According to the field observation, visible discoloration of the attacked tree crown started in July. The results did not show significant spectral differences between the experimental and control plot before attacks, so the condition of the hypothesis was fulfilled.

Index Terms— Forest damages, bark beetles, short-wave inferred, Sentinel-2, WorldView-3, vulnerability

1. INTRODUCTION

With the aggravation of global warming, the outbreaks of forest pests have happened more and more frequently and damaged a huge amount of forest. Detecting infestations at an early stage (green attacks) is considered to be important to avoid spreading. Remote sensing techniques can show forest vitality changes, but achieving early detection of the trunk-boring infestation is still challenging because the spectral changes are subtle. In recent years, the European spruce bark beetle (Ips typographus, L.) outbreaks have destroyed many forests in Europe, thus many studies have explored the possibilities of early detection using remote sensing data. Although many studies have shown the spectral differences between healthy and green-attacked forests [1, 2], several studies have also demonstrated that those differences existed before attacks, but the spectral differences did not increase during green attacks [3, 4], which means the spectral differences could not indicate infestation. This study will test this hypothesis and present when the infested forest showed a significantly different spectral signature when no significantly different signature could be observed before the infestations.

2. MATERIAL AND METHODS

2.1. Study area and field data

The study area is located at Remningstorp in southern Sweden (58°27’18’’N, 13°39’8’’E). In the spring of 2021, six spruce stands were selected, and eight circular field plots without infestations were set up in each stand with a radius of 15 m. All trees on the plots were inventoried for tree locations and diameter at breast height (DBH), i.e. 1.3 m above ground. In each stand, pheromone bags were put up in four experimental plots to attract bark beetles attacking the trees, and the other four plots were set up as control plots without infestations and pheromone bags. The trees in the experimental plots were inventoried every week, recording the infestation symptoms, including resin flew on the stem, number of holes in the bark, damage level of the bark, and discoloration and defoliation of the tree crown. According to the records, the first wave of attacks started at week 20 (May 17), and attacked trees started showing discolored tree crowns at week 27 (July 5, Figure 1). In total, 206 trees were attacked.

The number of attacked trees were used to categorize the plots as:

- Experimental plots:
  - Severe infestation (6 plots, with > 10 damaged trees);
  - Moderate infestation (9 plots, with 5–10 damaged trees);
  - Mild infestation (9 plots, with < 5 damaged trees);
- Control plots (24 plots, with only healthy trees).

At the individual tree level, we labeled the trees as:
- Infested trees before image acquisition (attacked before 2021-06-13);
- Infested trees after image acquisition (attacked after 2021-06-13);
- Healthy trees in experimental plots (inventoried as healthy trees in October 2022);
- Healthy trees in control plots.

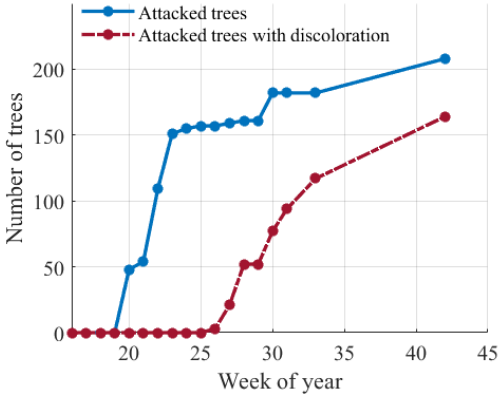

Figure 1. The number of attacked trees and the number of attacked trees with discolored crowns during the growing season.

2.2. Remote sensing data

We obtained eight cloud-free Sentinel-2 images during the growing season (April 16, June 13, June 20, June 28, August 19, September 13, October 18, October 23). We used the Level-2A product of Sentinel-2, a bottom-of atmosphere reflectance image. The resolution and wavelength of the used Sentinel-2 bands are listed in Table 1. The WorldView-3 SWIR image (Level-2A product) was obtained on June 13. At this time, most of the attacked trees have been infested for four weeks, showing no discoloration and defoliation (green-attack). The WorldView-3 SWIR image has eight bands with 3.7 m resolution (Table 2). We have also ordered Pleiades images and will add the results if a cloud-free image was obtained during the green attacks.

Table 1. Wavelength and spatial resolution of Sentinel-2 images.

Band Number	Central wavelength (nm)	Bandwidth (nm)	Spatial resolution (m)
Band 2 – Blue	492.4	66	10
Band 3 – Green	559.8	36	10
Band 4 – Red	664.6	31	10
Band 5 – Red-edge	704.1	15	20
Band 6 – Red-edge	740.5	15	20
Band 7 – Red-edge	782.8	20	20
Band 8 – NIR	832.8	106	10
Band 8A – Narrow NIR	864.7	21	20
Band 11 – SWIR	1613.7	91	20
Band 12 – SWIR	2202.4	175	20

Table 2. The wavelength of WorldView-3 SWIR images.

Band Number	Wavelength (nm)	Band Number	Wavelength (nm)
1	1195 – 1225	5	2145 – 2185
2	1550 – 1590	6	2185 – 2225
3	1640 – 1680	7	2235 – 2285
4	1710 - 1750	8	2295 – 2365

2.3. Methods

The mean pixel values were extracted for the 15 m radius plots from the Sentinel-2 and WorldView-3 SWIR images, and the mean pixel values of individual trees from the WorldView-3 images were also obtained with 1.5 m buffer according to the average crown diameter of 3 m. We used a two-sided Wilcoxon rank-sum test to test the significance of the spectral difference at the 5% significance level. Additionally, we computed the Kernel density distribution of the mean pixel values of different groups.

We plan to use machine learning methods to train the classification model using all bands to verify if green attacks could be detected using combinations of different bands.

3. RESULTS

3.1. Sentinel-2

For the Sentinel-2 images, no significant differences were observed between groups in April and June in any band. When comparing the spectral differences between the severely infested plots and control plots, significant differences were observed on the image in August in the bands 2, 4, 5, 11, and 12 (Table 3). Other bands showed significant differences in September.

When comparing the spectral difference between the moderately infested plots and control plots (Table 4), a significant difference was first shown in the August image, but only for the band 4 (red band). In the later images, the bands 2, 4, 11, and 12 showed significant differences. The bands 3, 5, 6, 7, 8, 8A did not show significant differences in any image.

No significant differences were observed between the mild-infested and control plots on any image of any band. Figure 2 shows the mean pixel values of different plot groups in April, June, August, and October.

Table 3. Significance of the spectral difference between the severely infested and control plots, with 1 indicating significant difference and 0 no significant difference.

Band No	Apr. 16	Jun. 13	Jun. 20	Jun. 28	Aug. 19	Sept. 13	Oct. 18	Oct. 23
2	0	0	0	0	1	1	1	1
3	0	0	0	0	0	1	1	1
4	0	0	0	0	1	1	1	1
5	0	0	0	0	1	1	1	1
6	0	0	0	0	0	1	0	0
7	0	0	0	0	0	1	0	1
8	0	0	0	0	0	1	1	1
8A	0	0	0	0	0	1	0	0
11	0	0	0	0	1	1	1	1
12	0	0	0	0	1	1	1	1

Table 4. Significance of the spectral difference between the moderately infested and control plots, with 1 indicating significant difference and 0 no significant difference.

Band No	Apr. 16	Jun. 13	Jun. 20	Jun. 28	Aug. 19	Sept. 13	Oct. 18	Oct. 23
2	0	0	0	0	0	1	0	1
3	0	0	0	0	0	0	0	0
4	0	0	0	0	1	1	1	1
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0
8A	0	0	0	0	0	0	0	0
11	0	0	0	0	0	1	1	1
12	0	0	0	0	0	1	1	1

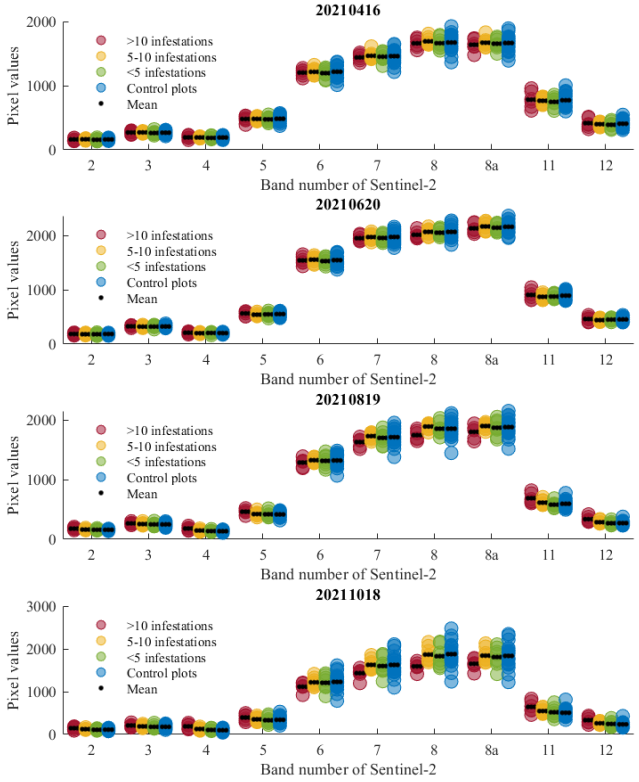

Figure 2. Mean pixel values from Sentinel-2 for different plot groups.

3.2. WorldView-3

No significant differences were observed in the WorldView-3 SWIR image between any plot groups (Figure 3). At the individual tree level, the trees attacked before the image acquisition showed significant differences in bands 8 ($p = 0.09$) compared to the healthy trees in attacked plots, but no significant differences compared to the healthy trees in the control plots. No significant differences were observed in any other bands between any tree groups.

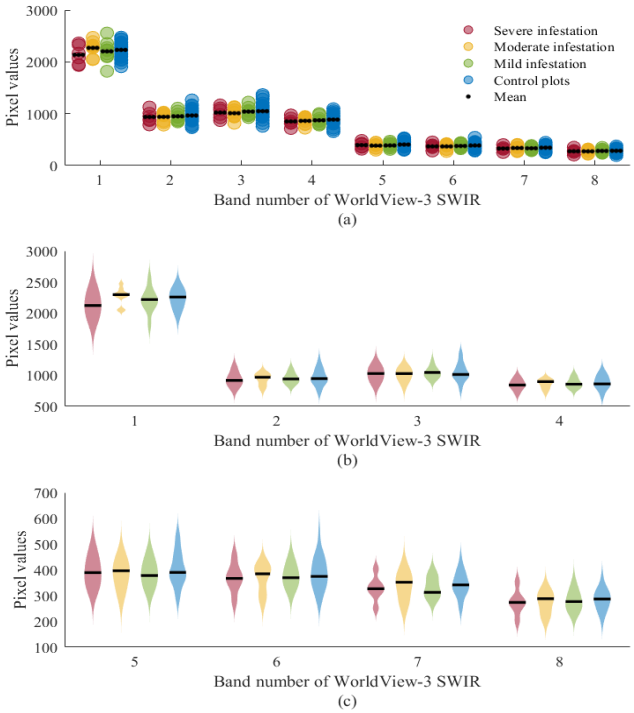

Figure 3. Mean pixel values from WorldView-3 SWIR for different plot groups. **(a)** Mean pixel values from all bands. **(b)** Kernel density distribution of the mean pixel values from bands 1 – 4. **(c)** Kernel density distribution of the mean pixel values from bands 5 – 8.

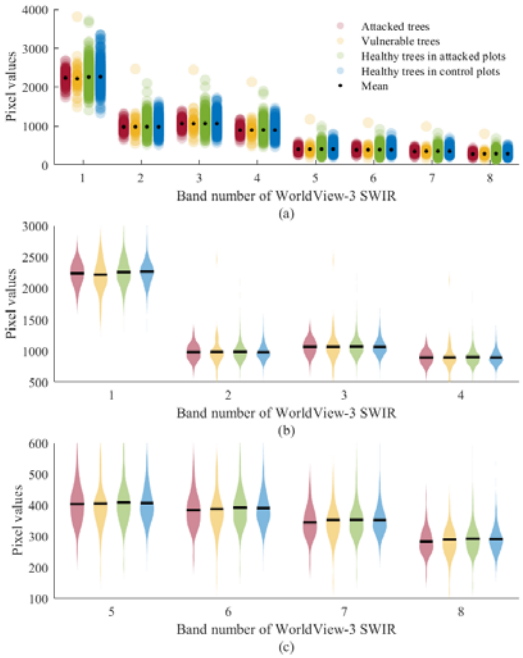

Figure 4. Mean pixel values from WorldView-3 SWIR for different tree groups. **(a)** Mean pixel values from all bands. **(b)** Kernel density distribution of the mean pixel values from Bands 1 – 4. **(c)** Kernel density distribution of the mean pixel values from Bands 5 – 8.

4. DISCUSSIONS AND CONCLUSIONS

In this study, we tested the spectral difference between healthy spruce plots and those attacked by the European bark beetles. We hypothesized that the spectral differences between the healthy and attacked trees do not increase during green attacks. We used 48 plots without significant spectral differences on the Sentinel-2 images before spring 2021 and conducted a controlled infestation in 24 of them, resulting in severe, moderate, and mild infestation during the summer. In the Sentinel-2 images, the infested plots did not show significant spectral differences compared with the healthy ones in the image in June, two months after the attacks. The severely infested plots started showing significant spectral differences in the Sentinel-2 image on August 19, while the moderately infested plots only showed significant differences in band 4 (red band) in the image of August 19. Other bands showed significant differences in the image of September 13. The hypothesis was verified in the Sentinel-2 images.

The results also illustrated the limitation of Sentinel-2 images on detecting small groups of infested trees. The Sentinel-2 images did not show significantly different spectral values when less than five trees were attacked in a plot (15 m radius, with 30-50 trees in total), not even in autumn when the infested trees had bright red crowns. For tree groups with 5-10 infested trees, the red band responded earlier, the blue and SWIR bands responded later, and the other bands did not respond in any image. This result also illustrates that the red, blue, and SWIR bands were more sensitive to infestations. This observation was consistent with previous studies.

Limited by the controlled experiment, we only obtained three plots with more than 20 attacked trees. They showed higher reflectance in the red-edge, NIR, and SWIR bands before the attacks, but the spectral differences with the control plots became smaller during green attacks (Figure 5). This phenomenon was also observed in the previous study and interpreted as the Sentinel-2 images captured the vulnerability[3]. We don't have enough data to verify it statistically in this study, but we assume that the higher reflectance could be used to estimate the risks of severe damage if attacked by bark beetles.

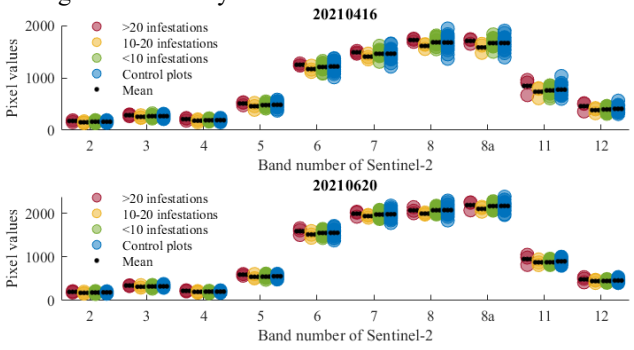

Figure 5. Mean pixel values from Sentinel-2 for different plot groups.

In the WorldView-3 image, no significant spectral difference was observed between different groups. The reflectance from the attacked trees was generally lower than the healthy ones. Both this study and previous studies showed higher reflectance from attacked plots when using lower resolution satellite images, e.g., Sentinel-2 images. Previous studies also showed higher reflectance from the attacked trees [4] when using higher resolution images such as aerial images [5], and the same with needles using a spectrometer. Therefore, more studies are needed to explore the reason for the lower reflectance from the attacked plots and trees in the WorldView-3 SWIR images.

ACKNOWLEDGEMENT

This study was funded by Stiftelsen Seydlitz MP bolagen, the data acquisition was founded by Hildur & Sven Wingquists Foundation for Forest Science Research, and the WorldView-3 image was provided by the MOST/ESA Dragon 5 Cooperation.

REFERENCES

[1] H. Abdullah, A. K. Skidmore, R. Darvishzadeh, and M. Heurich, "Timing of red-edge and shortwave infrared reflectance critical for early stress detection induced by bark beetle (Ips typographus, L.) attack," *International Journal of Applied Earth Observation and Geoinformation*, vol. 82, no. 2, p. 101900, 2019.

[2] H. Abdullah, A. K. Skidmore, R. Darvishzadeh, and M. Heurich, "Sentinel-2 accurately maps green-attack stage of European spruce bark beetle (Ips typographus L.) compared with Landsat-8," *Remote Sens Ecol Conserv*, vol. 5, no. 1, pp. 87–106, 2019.

[3] L. Huo, H. J. Persson, and E. Lindberg, "Early detection of forest stress from European spruce bark beetle attack, and a new vegetation index: Normalized distance red & SWIR (NDRS)," *Remote Sensing of Environment*, vol. 255, no. 7, p. 112240, 2021.

[4] V. Bárta, P. Lukeš, and L. Homolová, "Early detection of bark beetle infestation in Norway spruce forests of Central Europe using Sentinel-2," *International Journal of Applied Earth Observation and Geoinformation*, vol. 100, no. 6, p. 102335, 2021, doi: 10.1016/j.jag.2021.102335.

[5] A. Reichmuth, L. Henning, N. Pinnel, M. Bachmann, and D. Rogge, "Early Detection of Vitality Changes of Multi-Temporal Norway Spruce Laboratory Needle Measurements—The Ring-Barking Experiment," *Remote Sensing*, vol. 10, no. 2, p. 57, 2018, doi: 10.3390/rs10010057.