ADVANCES IN FOREST FIRE RESEARCH

2022

Edited by
DOMINGOS XAVIER VIEGAS
LUÍS MÁRIO RIBEIRO

Quick assessment of burn area and burn severity on black locust stands using Sentinel 2 imagery in South-West Romania

Adrian Lorenț[1,2]; Marius Petrila[1]; Vladimir Gancz[1]; Florin Capalb[1,2]; Bogdan Apostol[1]; Nicolae-Ovidiu Badea[1,2]

[1]*National Institute for Research and Development in Forestry (INCDS), "Marin Drăcea". Bulevardul Eroilor nr. 128, 077190 Voluntari, Ilfov, Romania,*
{adrian.lorent, marius.petrila, vladimir.gancz, bogdan.apostol}@icas.ro, {florin.capalb@yahoo.com}, {ovidiu.badea63@gmail.com}
[2]*Faculty of Silviculture and Forest Engineering, "Transilvania" University of Braşov. Str. Sirul Beethoven, nr. 1, 500123 Brașov, Romania*

**Corresponding author*

Keywords

Forest fires, black locust, burn severity, dNBR, Sentinel 2

Abstract

In Romania forest fires have a strong annual and seasonal variability, having a distribution pattern correlated with human activities like stubble burning practices. The most fire affected region is located in the southwest of Romania, in the counties of Mehedinți and Gorj with a mosaic landscape of forests with agricultural land and human settlements. Although the year 2021 was generally a mild fire season at national level, almost 60% of the forests burned area occurred in Mehedinți, county whose surface covers 2.06% of the national territory. The reported affected area is determined by measurements with GPS receivers or by an approximate estimate of the percentage of affected area in a forest parcel. The accuracy of those determinations is not being verified through other procedures like remote sensing-based methods, thus there is a need for independent evaluation of the reported fire impact. The aim of this research is to perform a quick robust enough assessment of the areas affected by forest fires in August 2021 and their severity in a forested area covered mostly by black locust (Robinia pseudoacacia), located in the southwestern part of Mehedinți county, using Sentinel 2 imagery and in field validation. In order to assess the degree of damage of the forest stands, Sentinel 2 satellite images were used, before, during and after the fire events. Additionally, official RGB and CIR aerial orthophoto images with a spatial resolution of 0.5 m from 2015 were used together with ultra-high resolution orthoimages obtained by processing RGB aerial photographs taken post-fire event with an UAV. Several remote sensing-based indices mostly used in forest fire-science literature were tested in order to extract the affected burn area and burn severity, among which the difference Normalized Burn Ratio (dNBR) proved to give the best estimates. A field inspection was carried out in order to verify whether the burn severity classes are corresponding to the ground truth impact of the fires. By comparing the dNBR mapping with terrain observations, we found that burn severity is corelated with canopy cover and height of the trees, at least in black locust stands, who naturally have lower canopy cover than other deciduous tree species. The correlation between dNBR and the canopy cover is negative, that means low canopy cover shows a false high severity on dNBR map and vice versa because the burnt grass and understory layer is more visible from above and denser in sparse forest stands. Also, low height of the trees induces high severity on the dNBR, the flames and heat produced by the burnt understory reaching easily to the canopy level. These observations were afterwards used to adjust the burn severity map.

1. Introduction

According to the last national disasters risk assessment (IGSU, 2016), forest fires in Romania have a low impact in terms of physical, economic and psychosocial consequences and a high probability of occurrence. In the last 65 years, Romania has recorded an average of 176 forest fires per year, with an average area of 917 ha per year and 5.2 ha per forest fire. However, since 2000 there was a significant increase in manifestation of this hazard, both in term of frequency and affected surface. The average number of forest fires per year increased to 319, while the affected area averaged 1867 ha. Since 2010 there was an appreciable increase in forest fires that affected areas over 25 ha. Most forest fires occur due to human activities, such as uncontrolled burning of stubble and dry grass in the fall and spring, on agricultural land in the forest neighborhood.

In Romania forest fires have a strong annual and seasonal variability, revealing that the distribution pattern correlates with human activities that are the predominant cause, while also influenced by prolonged periods of droughts which induces reduced combustible humidity (Lorent et al, 2018).

The most fire affected region is located in the southwest of Romania, in the counties of Mehedinți and Gorj, a region with a climate with Mediterranean influences, with mosaic landscapes of forests with agricultural land and human settlements. Although the year 2021 was below average in terms of the number of fires recorded at national level and the affected surface, out of a total of 278 forest fires which affected a surface of 2101.14 ha, 71 of them covering a surface of 1238.81 ha occurred in Mehedinți county, whose surface covers 2.06% of the national territory.

Even though Mehedinți is known as a fire prone area, 2021 was an exceptional year in terms of vegetation fires, which occurred with an unprecedented frequency, amid a period of drought and strong winds, coupled with the local practices of burning stubble and dry grass for clearing the land. According to the Inspectorate for Emergency Situations of Mehedinți county, between 1st of July and 30th of September 2021, there were 852 fires that started from brambles, shoots and dry vegetation, of which 35 fires occurred in the forests. Out of the 35 fires, 24 were surface fires and 11 damaged forest plantations. Practically, in July and August (and to some extent in September), military firefighters intervened daily to extinguish vegetation fires, which endangered community areas and even spread to several households.

After each forest fire intervention, a report is drawn up by the military firefighters and the forestry personnel in which the area affected and the damages caused are evaluated. The affected area is determined by measurements with GPS receivers or by an approximate estimate of the percentage of affected area in a forest parcel. The accuracy of those determinations is not being verified through other procedures like remote sensing-based methods, thus there is a need for independent evaluation of the reported fire impacts.

The aim of this research is to perform a quick and robust enough assessment of the areas affected by forest fires in August 2021and their severity in a forested area covered mostly by black locust trees (*Robinia pseudoacacia*), located in the southwestern part of Mehedinți county, using Sentinel 2 imagery and in field validation.

2. Materials and methods

2.1. Study area

The study area is located in Southwestern Romania, in Mehedinți county (Figure 1), being covered mainly by black locust forests installed on the river dunes in the high terrace of the Danube, where the forests are interspersed with cultivated or uncultivated agricultural land. The obligation to demonstrate that the agricultural lands are being cultivated (for obtaining subsidies in agriculture) makes the local practice, such as cleaning of dry grass and vegetable waste (after harvesting cereals) to be often based on the burning of stubble and of the uncultivated land. In conditions of prolonged drought and strong wind, during August – September 2021, these repeated fires led to the spread of dry vegetation fires in the forest stands, resulting in thousands of hectares of burned agricultural fields and forests, with varying degrees of damage.

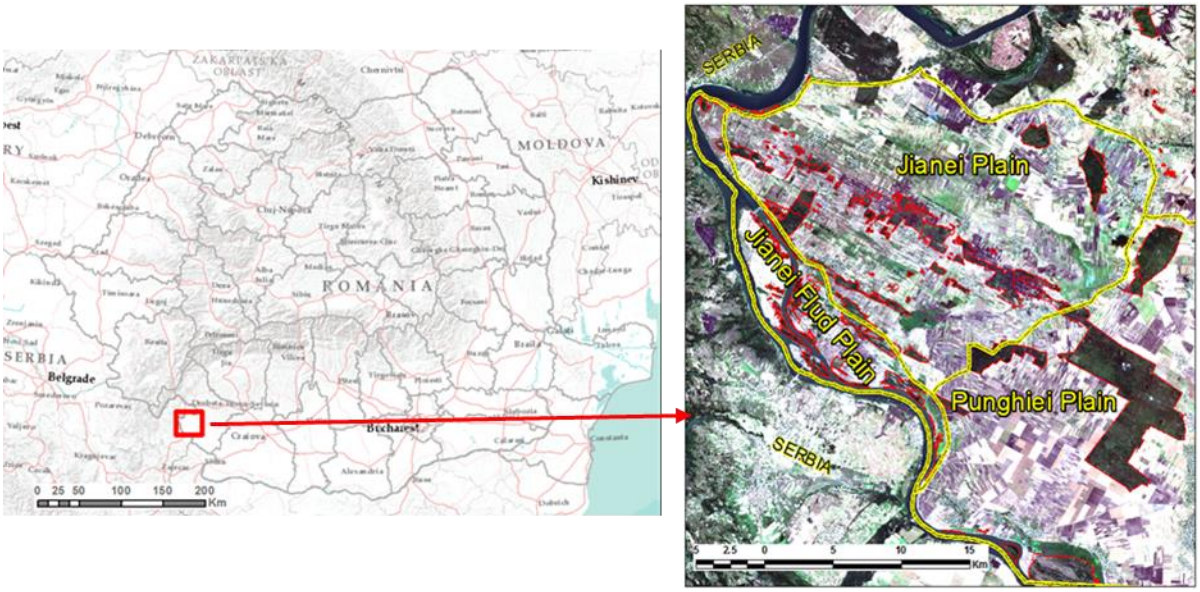

Figure 1 - Location of the study area

2.2. Materials

In order to assess the degree of damage of the forest stands, a methodology for estimating the severity of the forest fires was adopted, using Sentinel 2 satellite images recorded before, during and after the fire events. Additionally, official RGB and CIR aerial orthophoto, captured in 2015 with a ADS80 camera, with a spatial resolution of 0.5 m, were used together with ultra-high resolution orthoimages obtained by processing RGB aerial imagery taken with a DJI Mavic 2 Enterprise Dual drone about a month after the fire events.

Sentinel 2 satellite imagery were downloaded from Copernicus Open Access Hub (https://scihub.copernicus.eu/dhus/#/home). A total of 9 images of 2A processing level (bottom-of-atmosphere reflectance ortho-image product) have been found and used within the study, covering the period between 1st of August and 8th of September 2021, in which most of the forest fires occured. All imagery was stacked by bands (except B1, B9 and B10), clipped for study area and re-projected into Stereografic 1970 *(*national Romanian cartographic projection). For rapid evaluation were picked up two images, one before fire (2021-08-01) and another one after fire was finished (2021-08-11). In Figure 2 is displayed a representative detail from study area on both images.

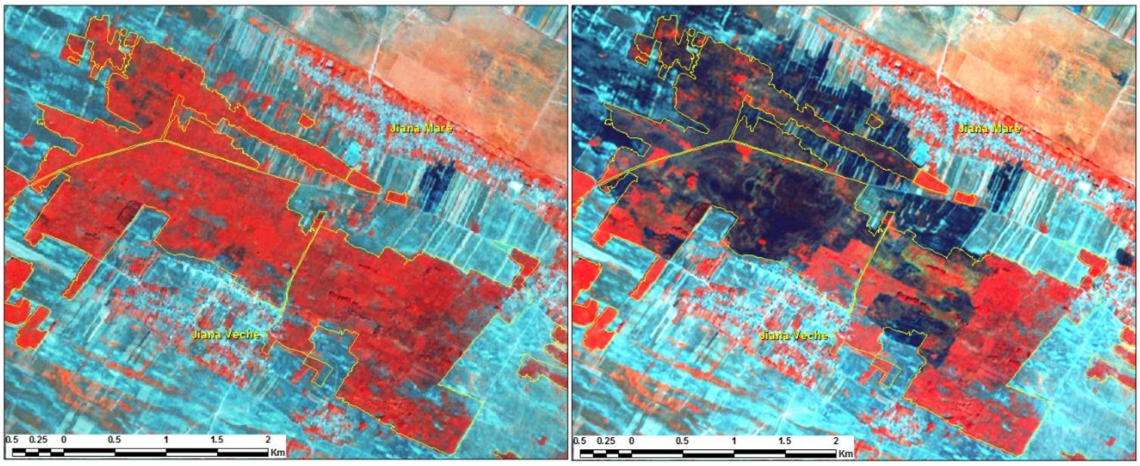

Figure 2 - Sentinel 2 images from study areas: 2021-08-01 (left – before the fire events), 2021-08-11 (right – after the fire events). Color combination: RGB = B8, B3, B2. Yellow line – forest limits

Forest fires incidents reports, containing detailed information about the fire events reported by the forest districts, were obtained from the Ministry of Environment, Waters and Forests. In total there were 8 forest fire events in August 2021 for the study area, totalizing 518.8 hectares of fire affected forests.

Forest management maps and plans were used to inform about the stand characteristics and to delineate the managed forest area within the study site.

2.3. Field data collection

After mapping the severity of forest fires based on satellite images, a field inspection was carried out in order to verify whether the burn severity classes are corresponding to the ground truth impact of the fires. For this purpose, several stands with different degrees of severity and with different characteristics in terms of height and canopy cover were identified on the map of severity degree obtained. The categories of land without forest vegetation, plantations, young, short trees, with height of up to 10 meters and mature trees with a height of over 10 meters, all with low, medium and high densities, were taken into account. They were then visited in the field to estimate of the actual degree of damage. The filed data collection was carried out in October 2021, one month after the forest fires took place.

In order to establish the degree of damage to the stand, a severity scale was developed to systematize and standardize the way it is evaluated according to the visible effects on the ground and on aerial images on the stand, broken down by the size of the stand (correlated with age) and stand density. The burn severity represents the degree or extent of the change in the environment caused by the fire. The change can be represented by simple or multiple biophysical variables on a continuous scale from no change to major changes. No universal standards are defined for describing the severity from an ecological point of view, although there are attempts to structure it in accordance with estimation based on remote sensing methods. For the field estimation of severity, 5 severity classes, similar to Key C.H and Benson N.C., 2006, were considered: unburned, low, moderate-low, moderate-high and high. The severity of fire was visually assed in the field for the four strata: substrate, herbs and low shrubs, tall shrubs and low trees and tall trees assigning a value ranging from 0 (unburned) to 4 (high severity). In total, 40 field plots with a surface of 20X20 meters were established. The classes were adapted to the specifics of the black locust stands from the study region and presented in Table 1.

Table 1 – Synthetic criteria for assessing forest fire severity in the field

Severity class	**Field classification criteria – synthetic description**
unburned	• The soil and the vegetation strata are unaffected by fire Substrates—Inert surface materials of soil, duff, litter, and downed woody fuels.
low	• duff is unaffected • burnt litter and herbs layer, shrub layer and seedling up to 1m high are partially affected • seemingly unaffected plantations • short (young) trees with unaffected foliage • tall (mature) tree with blackened trunks up to 0.5 m
moderate-low	• duff layer is partially affected • burnt litter and herbs layer, shrub layer and seedling are heavily affected • plantations are visibly affected • short (young) trees with the foliage partially dry • tall (mature) tree with blackened trunks up to 1 m
moderate-high	• the organic soil is charred • burnt litter and herbs layer, shrub layer and seedling are charred • the plantations are charred, return possible only after the cutting above the collar • short (young) shrub with crown affected by scorch or girdle • tall (mature) shrub with blackened trunks up to 2 m, the lower part of the crowns affected by scorch or girdle
high	• the soil organic layer is transformed into ash • litter and herbs layer, shrub layer and seedling are transformed into ash • plantations are torched, the stems are consumed by fire • short (young) shrub with crown affected by scorch or girdle, the stems are carbonized • tall (mature) shrub with blackened trunks over 2 m, more than 50% dry or burnt foliage in the upper part of the crown

Representative areas were aerial photographed with a DJI Mavic 2 Enterprise Dual UAV system at the same time with the field sampling campaign and high resolution (i.e., 40 cm) orthoimages were derived. The field observations were used afterwards to adjust the predefined burn severity classes according to the severity classes depicted in the field.

2.4. Image processing

First step was to calculate several remote sensing-based indices recommended by forest fire-science literature using formulas adapted for Sentinel 2 (Mallinis et all, 2018) such as: NBR, NDVI, GNDVI, NBRn, NDVIRE1, NDVIRE1n, CIRE1, MSRRE1, MSR, RE1n and PCA (PC1) for each of both images and, also bitemporal indexes: dNBR, RdNBR, RBR, dNBRn and dNDVI, dPC1. Each result was studied visually, by comparing between them and the satellite imagine from 2021-08-11. Visual inspection of the results indicated that the differenced Normalized Burn Ratio (dNBR) index showed the best results in estimating the fires severity for the study area. The dNBR severity classes were firstly classified according to Key and Benson (2006) thresholds. In Figure 3 the burn severity classes derived from the dNBR index are showed for one of the area most affected by fire.

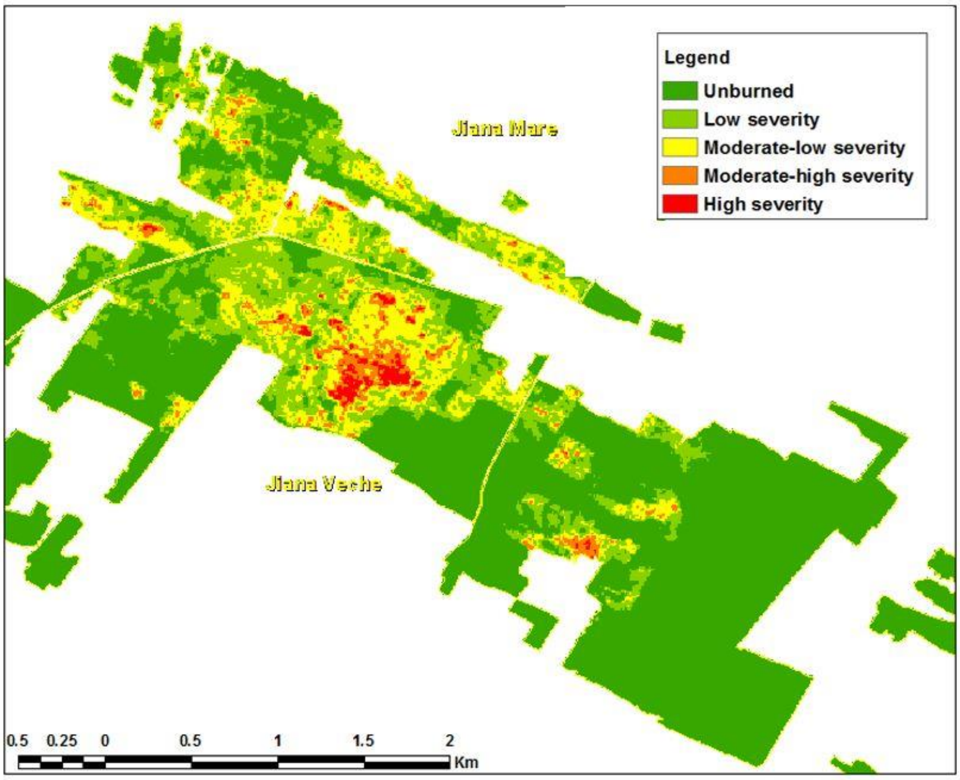

Figure 3 - dNBR: images S2 2021-08-01 (before), 2021-08-11 (post). Yellow line – forest limits

After a detailed visual inspection in accordance with S2 image from 2021-08-11 it was observed that the dNBR thresholds of Key and Benson (2006) are not very appropriate for this area. Consequently, using data collected from the field, the thresholds were adjusted to fit as best as possible the severity classes depicted in the field. In the Table 2 are shown the thresholds used in this study compared with the Key and Benson's thresholds.

Table 2 – The dNBR fire severity thresholds

Key and Benson's thresholds	Thresholds used in this study	Severity class
-0,360 – 0,100	-0,364 – 0,139	Unburned
0,100 – 0,269	0,139 – 0,319	Low severity
0,269 – 0,439	0,319 – 0,456	Moderate – low severity
0,439 – 0,659	0,456 – 0,568	Moderate – high severity
0, 659 – 0,999	0,568 – 0,999	High severity

In figure 4 is presented a detail of the severity map adjusted with the terrain.

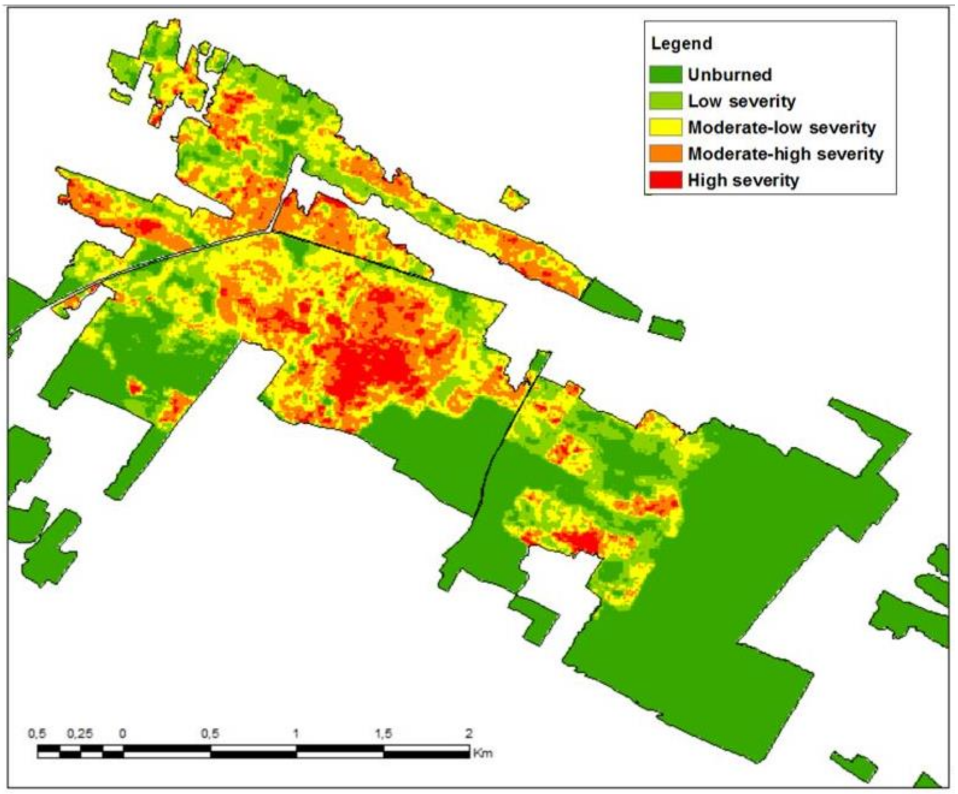

Figure 4 – dNBR: Result of using the adjusted thresholds.Images S2 2021-08-01 (before), 2021-08-11 (post). Black line – forest limits.

First visual inspection of the result, by comparing with S2 image before the fire (see figure 2) and then a field inspection was carried out in order to verify whether the burn severity classes are corresponding to the ground truth impact of the fires, we found that burn severity is in accordance with canopy cover and height of the trees, at least in black locust stands, who naturally have lower canopy cover than other deciduous tree species. The correlation between dNBR and the canopy cover is negative, that means low canopy cover shows a false high severity on dNBR map and vice versa because the burnt grass and understory layer is more visible from above and denser in sparse forest stands. Also, low height of the trees induces high severity on the dNBR, the flames and heat produced by the burnt understory reaching easily to the canopy level.

In order to increase the accuracy of the fire effects map, based on dNBR, a digital map of canopy closure and height of the trees was produced, within GIS environment, based on the aerial, colour infrared (CIR) of 0.5 m spatial resolution captured in 2015. The classes were delineated through manual vectorization and the canopy closure and height classes were visually established through photo-interpretation.

For the height of the trees, three classes were considered, namely plantations (artificial culture of young trees, with the canopy not yet developed), short trees (height below 10 m), tall trees (height over 10 m). The classes were established after it was found in the field that the vulnerability to the fires was inversely proportional to height of the trees. For canopy closure four categories were established: without canopy, low 0.1-0.3, medium 0.4-0.6 and high de 0.7-1.0. The stands with low canopy closure appear to be more severely affected than in reality on satellite images.

It has to be mentioned that for the studied area are not any managements plans and maps to provide such information. Beside this, in the management plans, the canopy cover and height of the trees are given as an average for the entire parcel or subparcel which is not useful for the study. Within figure 5 an example on an aerial CIR image is presented.

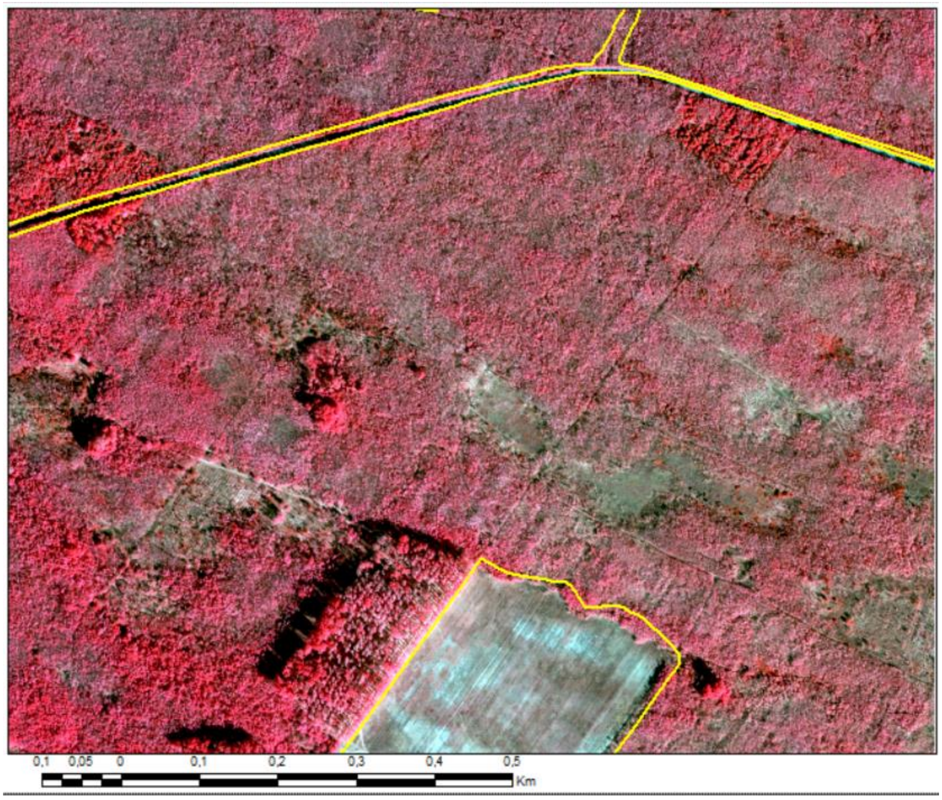

Figure 5 – Aerial image (CIR), 0.5 m, within the area (detail) showing high inhomogeneity of the canopy cover and trees height. Yellow line – forest limits

Moreover, it was found that in the young black locust stands (young trees were considered to be those with a height of up to 10 m, this being the approximate limit to which the heat released by surface fires affects the foliage) are most affected by surface fires (fed by tall, dry grass, litter and sometimes shrub state). Shrubs with an average height of more than 10 m were the least affected, as the thicker bark and the height of the canopy make them less vulnerable. Estimation of severity on images tends to be overestimated in the case of low stands and underestimated in the case of tall stands compared to that estimated in the field. In the stands with a lower canopy closure (as is the case with black locust), the grass developed more, providing more fuel for burning, being seconded by a higher visibility from the air / space of the burned soil. In dense trees, which cover the ground well (in the case of trees with oak species), grass and shrubs do not grow, so the surface fire is fed only by litter and the green canopy can hide the real severity. The estimation of severity on images tends to be exaggerated in the case of rare trees and underestimated in the case of dense trees, compared to that estimated in the field. A special case is the one of the plantations, which are very vulnerable due to their small age (and size), large amounts of fuel (tall, dry grass), which have no canopy and in which the soil is exposed. This is the case where the estimated severity on aerial or satellite images is usually underestimated, as they can be severely affected even by low-intensity surface fires. The presence or absence of fire-affected foliage is the factor that makes the estimation of severity based on aerial / satellite images different from the ground truth severity. This makes the estimate closer to reality in the case of deciduous trees and in leaf-off periods. A key proposal for correcting the estimated severity on aerial / satellite imagery based on the criteria set out above is presented in Table 3.

Table 3. Key for correcting the estimated severity derived from Sentinel 2 imagery (the dNBR index)

Sentinel 2 severity Based on dNBR index		**Real ground severity correction**					
	Plantation	**Short stand (tree heights ≤ 10 m)**			**Tall stand (tree heights >10 m)**		
		canopy cover			**canopy cover**		
		low 0,1-0,3	medium 0,4-0,6	high 0,7-1,0	low 0,1-0,3	medium 0,4-0,6	high 0,7-1,0
1 unburned	unburned	unburned	unburned	unburned/ low severity ↑	unburned	unburned	unburned / low severity ↑
2 low severity	moderate – low severity↑	low severity	low severity	low severity	low severity	low severity	moderate – low severity ↑
3 moderate–low severity	moderate – high severity↑	low severity ↓	moderate -low severity	moderate – low severity	low severity ↓	moderate – low severity	moderate-high severity ↑
4 moderate–high severity	high severity↑	moderate – low severity↓	moderate – high severity	moderate – high severity	moderate – low severity↓	moderate-high severity	high severity ↑
5 high severity	high severity	moderate – high severity↓	high severity	high severity	moderate – high severity↓	high severity	high severity

The dNBR raster map of was converted into a vectorial map of severity (5 classes). This strata was afterwards intersected with the layer representing the canopy cover and the trees height classes. The severity classes were adjusted according to the correction key from Table 3. Within figure 6 it is shown a detail of the new severity map, thus obtained.

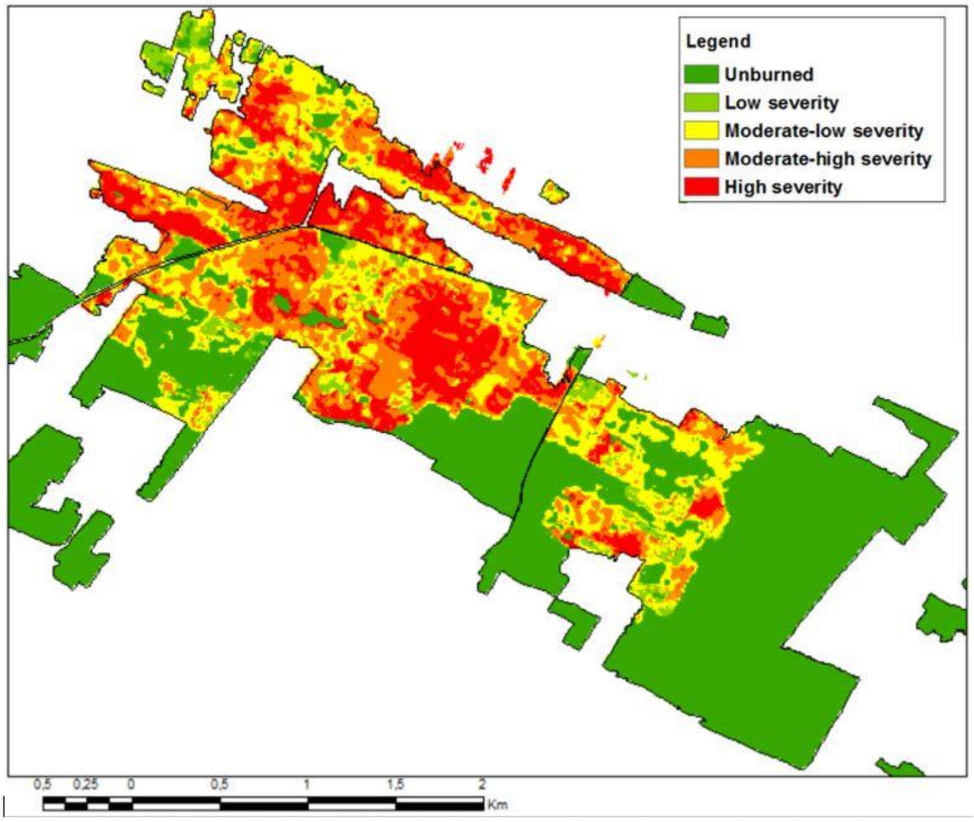

Figure 6 – The new severity map corrected based on canopy cover-trees height map. Black line – forest limits

The final adjusted severity map shows that the severity was lowered in the case of stand with low stand canopy cover considering the fact that the dNBR tends to amplify the severity because the pixels receive much of the signal from the ground level and higher in case of dense and tall stands.

3. Results and discussion

The analysis of different indices found in specialty literature (Llorens, R. et al. 2021, Mallinis G. et al. 2018, Llorens, R. et al. 2021) showed that the dNBR index was the most suitable for burn severity estimation, showing more accurate results, at least for our study area.

The dNBR map shows a severity distribution apparently close to the severity visually estimated on Sentinel 2 image from 2021-08-11 date. A more detailed analyze showed that burn severity depends on the canopy cover and height of the trees, at least in black locust stands, who naturally have lower canopy cover and subsequently canopy density than other deciduous species. This was first observed on Sentinel 2 imagery before fire (2021-08-01), on the aerial imagery (2015-05-30) and also was confirmed in the field. The relation between dNBR and canopy cover confirm that low canopy cover shows a false high severity on dNBR map and vice-versa, due to the burnt grass and understory layer is more visible from above and denser in sparse forest stands. Also, low height of the trees induces high severity on the dNBR, the flames and heat produced by the burnt understory reaching easily to the canopy level. This observation had to be used to adjust the burn severity map. The stands with low canopy cover, but high trees, could have in reality lower severity resulting from dNBR because if only surface fuel is burned and the trees are not really affected, on the imagery the signal coming from ground will be dominant for this spatial resolution and dNBR will be high. Into the dense and taller stands, with the same surface burned severity, the signal will be dominated by canopy, which is less affected. These stands could show on dNBR "unburned severity level", even the real severity could be different (from "low" to "medium-low" or even higher), if the upper canopy was not affected. Concerning low height forest stands with, the situation will be different even if density is high or low, because the tree crowns could be highly damaged by surface fire and the severity could be high, which is not the case of high trees stands. In the case of other tree species from the area, like Scots pine (*Pinus sylvestris*), the effect was more serious, stands were burned up to the top and severity put into evidence by dNBR was closer to the reality. Gibson et al. (2020) also found, using Sentinel imagery to evaluate the fire severity in eastern Australia that higher canopy cover and higher topographic complexity was associated with a higher rate of under-prediction, due to the limitations of viewing the burnt understorey of low severity classes. In terms of the fire affected area, we found that the affected area reported by the forestry districts was close to that obtained from Sentinel 2 imagery.

Concerning the forest surface affected by fires, a total of 8 fire incidents were reported by the forestry districts for the study area between the period of 04-11 August 2021 with a total forest affected surface of 518.8 ha. Our satellite imagery analysis showed that in total there were affected 756,3 ha, thus resulting an underreported surface of 237.5 ha. A one-to-one evaluation comparison of each forest fire incident in terms of affected area could not be carried out due to the relatively low temporal resolution of the Sentinel imagery (i.e., 5-day revisit time) and because it was hard to distinguish on imagery with high confidence what was the surface affected by each fire because some of the fire merged together in a single, bigger one.

4. Conclusions

Sentinel 2 imagery can by successfully used to estimate the burned area and the burn severity in stands dominated by black locust. For a more accurate estimation of burn severity levels for black locust stands more situations need to be considered in terms of density cover and height of the trees. Moreover, the study reveals only a first step for the assessment of the areas affected by fires, presenting a quick and robust enough assessment method.

5. Acknowledgements

This research was funded partially by Romanian Ministry of Research, Innovation and Digitization and Innovation, within the Nucleu BIOSERV National Programme (Contract No. 12N/2019), Project ID PN 19070108 and the H2020 project FirEURisk.

6. References

Delcourt, C. J. F., Combee, A., Izbicki, B., Mack, M. C., Maximov, T., Petrov, R., Rogers B.M., Scholten R.C., Shestakova T.A., Wees, Dave van, Veraverbeke, S. (2021). Evaluating the differenced normalized burn ratio for assessing fire severity using sentinel-2 imagery in northeast siberian larch forests. Remote Sensing, 13(12), 1–20. https://doi.org/10.3390/rs13122311

Gibson, R., Danaher, T., Hehir, W., & Collins, L. (2020). A remote sensing approach to mapping fire severity in south-eastern Australia using sentinel 2 and random forest. Remote Sensing of Environment, 240(September 2019), 111702. https://doi.org/10.1016/j.rse.2020.111702

IGSU, (2016) Country report, 5.1 Conditionality, Romania (Raport de țară, Condiționalitatea 5.1, România). https://www.igsu.ro/Resources/COJ/RapoarteStudii/Raport_Final_de_tara%20pt%20Condit%20ex-ante%202016.pdf

Key, H.C., Benson, N (2006). Landscape Assessment: Ground measure of severity, the Composite Burn Index; and Remote sensing of severity, the Normalized Burn Ratio. In book: FIREMON: Fire Effects Monitoring and Inventory System. Edition: RMRS-GTR-164. Publisher: USDA Forest Service, Rocky Mountain Research Station, Ogden, UT

Llorens, R., Sobrino, J. A., Fernández, C., Fernández-Alonso, J. M., & Vega, J. A. (2021). A methodology to estimate forest fires burned areas and burn severity degrees using Sentinel-2 data. Application to the October 2017 fires in the Iberian Peninsula. International Journal of Applied Earth Observation and Geoinformation. https://doi.org/10.1016/j.jag.2020.102243

Lorenţ, A., Neagu, Ș., Petrila, M., Apostol, B., Gancz, V., Mitsopoulos, I., Mallinis, G., 2018. Evaluarea hazardului la incendii de pădure la nivel de unitate administrativ-teritorială în perioada 2006-2015. [*Forest fire hazard assessment at territorial administrative unit level during 2006-2015 period*]. Revista Pădurilor nr. 4/2018, ISSN print 1583-7890, ISSN online: 2067-196. p. 37-58.

Mallinis G., Mitsopoulos I., Chrysafi I. (2018). Evaluating and comparing Sentinel 2A and Landsat-8 Operational Land Imager (OLI) spectral indices for estimating fire severity in a Mediterranean pine ecosystem of Greece, GIScience & Remote Sensing, 55:1, 1-18, DOI: 10.1080/15481603.2017.1354803