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Assessment of Burn Area and Vegetation Dynamics at Two Forest Sites Located in South Albania

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Abstract

Wildfires present a significant threat to forest ecosystems, with large impacts on carbon dynamics, biodiversity, and air quality. This study aimed to map the fire-affected forests and evaluate vegetation dynamics at two sites (Kutal and Riban) located in southern Albania. Burned areas and vegetation activity were identified and mapped using fire/vegetation spectral indices, the Normalized Burned Ratio (NBR) and NBR_2/Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), derived from processing the Landsat 8 satellite images in a GIS system. The difference between pre- and post-fire NBR was used to compute the dNBR index and threshold classes were applied to obtain burn severity maps. Mapping accuracy of burned areas and severity was assessed using 50 geometrically structured field plots. The scaled difference dNBR index provided more reliable maps with higher degree of differentiation among burn severity classes than NBR_2 (92% vs. 72 % accuracy), revealing high and moderate burn severity in more than two-thirds of the affected forest site in Kutal (42 hectares, 69%) and approximately three-quarters of damaged forest in Riban (27 hectares, 82%). NDVI and EVI captured wildfire disturbance and tracked vegetation regrowth and recovery (mostly grass and shrubs) at both sites during the subsequent growing season. However, NDVI/EVI indices showed differences in evaluating vegetation recovery between sites, as they enhanced changes at Kutal/Riban, respectively. These findings are useful for forest managers in designing appropriate strategies for the post-fire management of the affected forests.

Keywords: forest, Landsat 8, spectral indices, burn area mapping, vegetation activity.

1. Introduction

Forest ecosystems are increasingly threatened by a variety of disturbances, especially wildfires, which have intensified in the recent decades, both in frequency and severity due to changing climatic conditions [1]. Wildfires affect the ecological functioning of many forest ecosystems as they modify vegetation moisture and composition, contribute to deforestation by burning vegetation layers, influence post-fire soil and vegetation processes such as soil erosion and vegetation regeneration [2]. Albania is characterised by environmental conditions that make it susceptible to wildfires, including climatic variability, land use patterns, and the influences of global climate warming [3–5]. Recently, in Albania an increase in wildfire occurrence has been observed, driven by both natural phenomena and human activities. Anthropogenic factors, including land mismanagement and illegal burning practices, exacerbate wildfire risks [4]. Moreover, the changing climatic conditions characterised by increases in temperatures and drought intensity and duration have raised vegetation vulnerability to wildfire, leading to losses in forest cover, biodiversity, and natural resources in general [3,5]. Therefore, wildfire management remains vital for environmental sustainability in Albania. Studies employing Remote Sensing and GIS have demonstrated that these technologies can enhance our understanding of fire severity and post-fire recovery [3]. Data provided by satellite images, combined with field-based observations are crucial for understanding the extent

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and severity of burned areas as well as assess and monitor the effects of wildfire on forest ecosystems. Accurate mapping of burned areas can be achieved either by using a single post-fire image or by combining satellite imagery from both the pre- and post-fire periods to clearly distinguish changes in vegetation [6]. One of the most frequently used indices for mapping burned areas and assessing burn severity on vegetation is the Normalized Burned Ratio (NBR) index [6]. The NBR index is highly specific and effective, providing a useful spectral signal for assessing the effects of wildfires on forest ecosystems, based on the available spectral bands [7,3]. By comparing pre- and post-fire images, NBR allows for the identification of forest areas affected by fire and offers a quantitative measure of burn severity [8]. Therefore, NBR has become an essential index for monitoring fire-affected forests, providing valuable data for forest management and post-fire recovery assessments [9].

Vegetation dynamics over time, including post-fire recovery, are widely assessed by means of indices derived from satellite images [10]. Among them, the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) are the most commonly used indices to monitor, quantify, analyse, and map vegetation cover and changes [11–14]. These indices can be analysed for both pre- and post-fire periods to obtain estimates of vegetation vigour, magnitude of damage, track vegetation regrowth, etc. [15]. In addition, GIS technology has been widely used in combination with Remote Sensing to further process, analyse and integrate data derived from satellite imagery interpretations, providing a comprehensive record of the site [16].

This study aimed to assess the fire-affected forests and to quantify the short-term post-fire vegetation dynamics at two forest sites located in southern Albania. These sites are of considerable significance as they encompass biodiversity-rich ecosystems that are highly susceptible to wildfires and increasingly vulnerable to the impacts of climate change. According to forest service data, in summer 2021 (30.07.2021), a wildfire burned more than 5.5 ha of pasture and shrubs, as well as 6.5 ha of *Pinus halepensis* plantation near Kutal village (hereafter S1), whereas in autumn 2019 (20.10.2019), a wildfire near Riban village (hereafter S2) burned more than 13.4 ha covered mostly by *P. hapelensis* plantation, with minor coverage of shrubs and grasses. The objectives were to: (1) map the burned areas and assess burn severity by means of the NBR index and its modified version, NBR_2, and (2) assess the post-fire vegetation activity via NDVI and EVI vegetation indices.

2. Materials and Methods

Study area

Study area is located in the middle part of Vjosa valley and includes two forest sites affected by wildfires (Figure 1). S1 is located within the administrative unit of Përmet, at coordinates 40°15'21.68"N and 20°19'59.18"E, altitude 303 m a.s.l., with southern, south-western, and western aspects, a slope of 45%, and grey-brown soils. S2 is situated within the municipality of Këlcyrë, at geographical position 40°19'22.96"N and 20°12'51.79"E, 283 m a.s.l., with a southern aspect, a slope of 15%, and grey-brown soils. The climate is characteristic of the Mediterranean, with mild and rainy winters and hot, dry summers, which supports a range of fire-adapted vegetation that can be easily ignited under extreme weather conditions [17]. Albania, like other Mediterranean countries, is facing significant challenges linked to climate change, characterized by prolonged drought periods and increased temperatures that create optimal conditions for wildfires [5].The interaction between climatic variables and wildfire risk is particularly pronounced in the country, where rising temperatures, altered precipitation patterns, and extreme weather events are expected to exacerbate fire susceptibility [5]. The study area is dominated by *Pinus halepensis* plantations associated with evergreen and deciduous Mediterranean shrubs in the understory, as well as herbaceous vegetation.

Remote Sensing data and analysis

The satellite data used in this study consisted of Landsat 8 images, available free of charge at the Earth Explorer website (https://earthexplorer.usgs.gov), with level 2 processing (radiometrically calibrated and georeferenced) (Table 1).

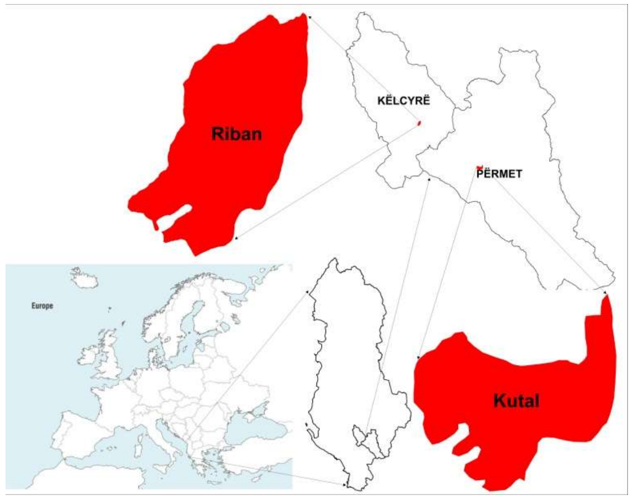

Figure 1. Study area

A large Landsat 8 database was explored, and four images covering the study area were selected close to the (pre- and post-) fire occurrence, to capture the immediate effects of fire on forest vegetation (Table 1). In addition, we selected two more images corresponding to the subsequent growing season to investigate the post-fire vegetation activity in the respective sites. Images were ordered and downloaded in the UTM projection (WGS_1984_UTM_ Zone_34N), and were used to calculate fire (NBR, NBR_2) and vegetation (NDVI, EVI) indices.

Table 1. Characteristics of Landsat 8 images used in the analysis.

Image name	Row/ path	Date	Cloud presence (%)
LC08_L2SP_186032_20210714_20210721_02_T1	186/32	14/07/2021	6
LC08_L2SP_185032_20210808_20210819_02_T1	185/32	08/08/2021	4
LC08_L2SP_186032_20190826_20200826_02_T1	186/32	26/08/2019	9
LC08_L2SP_186032_20191029_20200825_02_T1	186/32	29/10/2019	7
LC08_L2SP_186032_20200628_20210707_02_T1	186/32	28/06/2020	11
LC09_L2SP_186032_20220626_20230628_02_T1	186/32	26/06/2022	15

Burn area and severity assessment

The spatial distribution of burn severity within each site was assessed using the NBR spectral index. NBR was computed by considering near-infrared (NIR) and shortwave infrared (SWIR) spectral bands to highlight changes in ground cover [6].

$$NBR = \frac{(NIR-SWIR)}{(NIR+SWIR)}$$

For Landsat 8 satellite images:

$$NBR = \frac{(Band5 - Band7)}{(Band5 + Band7)}$$

To compare results regarding the assessment of fire-affected areas, a variation of the standard NBR index (NBR_2) was included in the study [18]. This index modifies the NBR index to highlight the sensitivity of vegetation to fluctuations in water content and is calculated using the formula:

$$NBR_2 = \frac{(SWIR_1-SWIR_2)}{(SWIR_1+SWIR_2)}$$

For Landsat 8 satellite images:

$$NBR_2 = \frac{(Band6 - Band7)}{(Band6 + Band7)}$$

To assess the burn severity and provide a quantitative estimate of the absolute change in NBR values, the difference between the pre- and post-fire conditions (dNBR) was calculated [6].

$$dNBR = NBR_{pre} - NBR_{post}$$

A linear grayscale was then applied to the boundaries of the dNBR image values, which increased the contrast between fire-affected and unaffected areas. This process enabled the identification of two forest areas affected by wildfire during the years 2019 and 2021, in the municipalities of Përmet and Këlcyrë. Changes in cover were carefully observed on the dNBR image to facilitate the subsequent process of digitizing the perimeter of the fire-affected areas. Burn severity within the digitized perimeter was categorized into five classes (Table 2) based on the dNBR index values [6].

Table 2. Classification of dNBR index values

Burn severity	dNBR value
Unburned	< 0.1
Low	0.1 to 0.27
Moderate	0.27 to 0.44
Relatively high	0.44 to 0.66
High	> 0.66

Field survey

The immediate effects of wildfire on forest vegetation were assessed and documented in the field by the forestry service a few weeks after the wildfire occurrence. Such data were important for this study to design the field work for the validation of burn severity maps produced. Based on the dNBR and $dNBR_2$ maps, 10 sampling plots were randomly selected on the map for each burn severity level (50 plots in total) and validated in the field [6]. Geographical coordinates of the centre of each plot were recorded using a GPS device (Garmin eTrex 10) and marked to be fully visible. From the centre of each plot, a 15-meter distance was measured in four cross directions to mark a squared sampling area with sides of 30m. The sampling plots were observed for several minutes to understand the extent of vegetation damage based on the visible evidence. Then, data on burn severity were collected at each site following the methodology described by Key and Benson, 2006. The accuracy assessment of burn severity maps was performed using an error matrix which represents the percentage of classification accuracy based on field observations [19]. The agreement between image classification and field data was assessed by the Kappa coefficient (K) [9].

Assessment of vegetation activity

To assess and analyse the dynamics of forest vegetation, pre- and post-fire, two vegetation indices derived from Landsat 8 satellite images were used: the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI). The NDVI index integrates the two most important spectral bands for distinguishing vegetation; near infrared (NIR, reflected by vegetation) and red (RED, absorbed by vegetation) [20]. NDVI is calculated using the following formula:

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

For Landsat 8 satellite images:

$$NDVI = \frac{(Band5 - Band4)}{(Band5 + Band4)}$$

The EVI index was used as a complement to the NDVI index, as it provides more accurate data on photosynthetic activity in areas with dense biomass [11]. EVI is computed with the formula:

$$EVI = 2.5 * \frac{(NIR - RED)}{(NIR + 6RED - 7.5BLU + 1)}$$

For Landsat 8 satellite images:

$$EVI = 2.5 * \frac{(Band5 - Band4)}{(Band5 + 6 * Band4 - 7.5 * Band2 + 1)}$$

GIS analysis

The GIS system was employed to clip the satellite images of the study area using the boundaries of municipalities of Përmet and Këlcyrë; to calculate and classify the burn severity indices NBR, NBR_2 and their difference values (dNBR, $dNBR_2$), to digitise the perimeter of fire-affected forest area based on dNBR maps, to calculate the accuracy of burn severity maps, to compute the vegetation indices (NDVI and EVI), and to produce and export the layout maps.

3. Results

Mapping accuracy and burn severity

Based on the differenced NBR and NBR2 images, we obtained the maps of fire-affected forests at the study area (Figure 2). The overall mapping accuracy was 90.00% (45 out of 50 plots classified correctly) and 72.00 % (36 out of 50) for dNBR (A) and $dNBR_2$ (B) maps, respectively (Table 3). The Kappa coefficient showed an agreement of 0.86 and 0.71 between imagery classification and field data for dNBR (A) and dNBR2 (B) maps, respectively. Kappa values greater than 0.77 represent substantial agreement between imagery classification and field assessments [9]. Consequently, we present only the results achieved with the dNBR index, as it is the most accurate and reliable. The largest part of the forest site (mostly north-east, south and west) near S1 presented "high" level of burn severity and consisted mostly of shrubs and *P. halepensis* trees (Figure 2). The remaining classes together (unburned, low, moderate, relatively high) covered less than half of the affected area, of which only a small portion was unburned (Figure 2, Table 4).

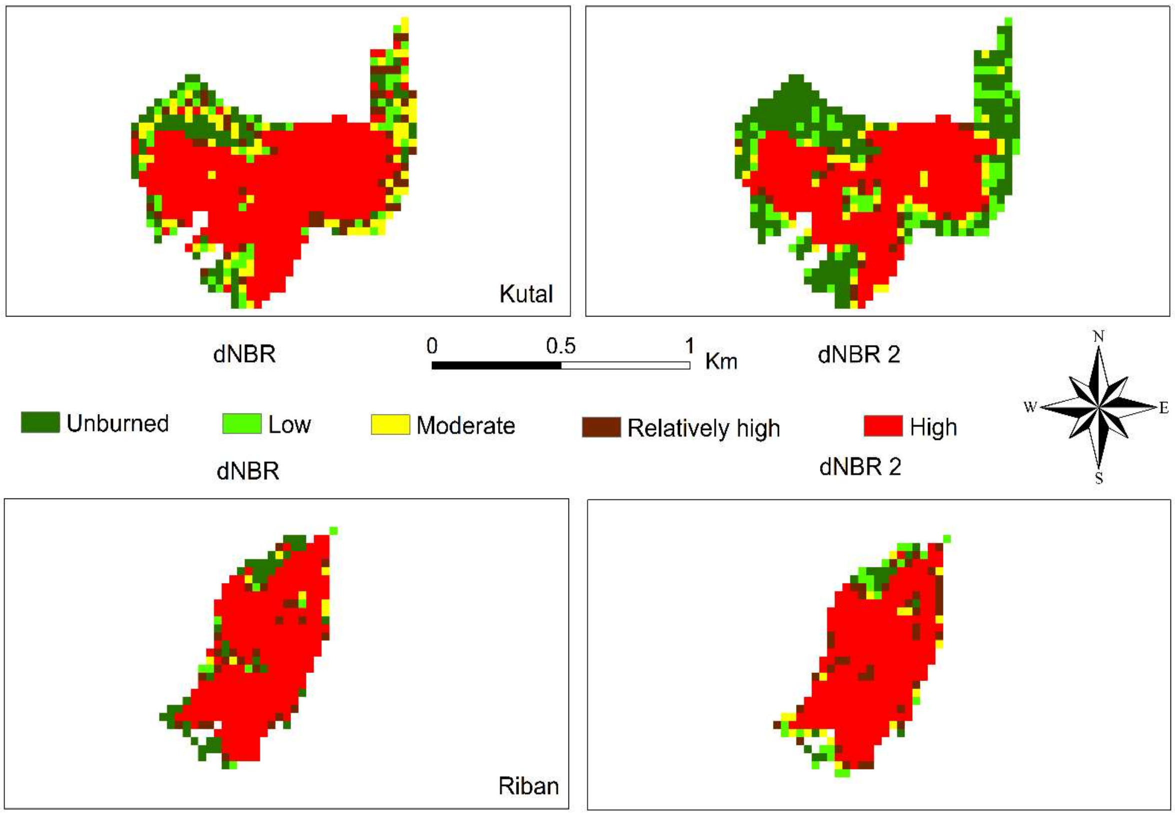

Figure 2. Burn severity maps of the forest sites affected by fires in 2019 (Riban) and 2021 (Kutal), according to the dNBR and $dNBR_2$ indices.

Table 3. Accuracy assessment results of forest sites damaged by fire, according to the dNBR (A) and $dNBR_2$ (B) index

(A) Error matrix	Unburned	Low	Moderte	Relatively high	High	Total
Unburned	**9**	0	1	1	0	11
Low	0	**10**	0	0	0	10
Moderate	1	0	**9**	0	0	10
Relatively high	0	0	0	**9**	1	10
High	0	0	0	0	**9**	9
Total	10	10	10	10	10	45
(B) Error matrix	Unburned	Low	Moderate	Relatively high	High	Total
Unburned	**5**	1	1	0	1	8
Low	3	**8**	1	0	0	12
Moderate	2	1	**8**	2	1	14
Relatively high	0	0	0	**8**	1	9
High	0	0	0	0	**7**	7
Total	10	10	10	10	10	36

Almost the entire S2 showed "high" burn severity whereas the remaining classes were distributed in the peripheral parts (mainly the NW part) and presented a very low portion of the fire-affected area. For S1, 36.99 ha or 60.98% of the forest area showed "high" burn severity, while the area characterised by "low", "moderate" and "relatively high" levels of burn severity was estimated to be 8.31%, 10.53% and 7.86%, respectively (Table 4)

Table 4. Burn severity results (in hectares and %) assessed by the dNBR index.

Site	Total (Ha)	Unburned		Low		Moderate		Relatively high		High	
		Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
S1	60.66	7.47	12.31	5.04	8.31	6.39	10.53	4.77	7.86	36.99	60.98
S2	32.04	3.87	12.08	0.72	2.25	0.72	2.25	2.25	7.02	24.48	76.40
Total	92.7	11.34		5.76		7.11		7.02		61.47	

At S1, only 7.47 ha, or 12.31% of the area was unburned. At S2, 24.48 ha out of 32.04 ha or 76.40% presented "high" burn severity whereas the remaining part, characterized by "low", "moderate" and "relatively high" levels of burn severity was estimated to be 2.25%, 2.25% and 7.02%, respectively. At S2, only 12.08% or 3.87 ha of the area remained unburned. Comparing both sites, S1 resulted in a larger area affected by wildfire compared to S2, but the latter was the most "heavily burned".

Vegetation activity

Statistics of the vegetation indices showed reduction of mean NDVI and EVI values at both sites after the wildfire occurrence when compared to the pre-fire state (Table 5). Changes in vegetation indices (pre- and post-fire) were generally higher in NDVI than EVI. Photosynthetic activity of vegetation in the subsequent growing season (the following year) increased at both sites, as presented by higher values in NDVI (S1) and EVI (S2), respectively.

Table 5. Statistics of the vegetation indices for the fire-affected forest sites.

Site	Statistics	Pre-fire NDVI	Post-fire NDVI	dNDVI	Pre-fire EVI	Post-fire EVI	dEVI
S1	Mean (St. dev.)	0.47 (0.1)	0.36 (0.15)	0.11 (0.14)	0.26 (0.06)	0.2 (0.09)	0.06 (0.09)
S2	Mean (St. dev.)	0.53 (0.12)	0.44 (0.11)	0.11 (0.11)	0.29 (0.07)	0.19 (0.07)	0.1 (0.01)
Site	Statistics	Post-fire NDVI	+1-year NDVI	dNDVI	Post-fire EVI	+1-year EVI	dEVI
S1	Mean (St. dev.)	0.36 (0.15)	0.57 (0.1)	0.21 (0.12)	0.2 (0.09)	0.35 (0.08)	0.15 (0.1)
S2	Mean (St. dev.)	0.44 (0.11)	0.51 (0.08)	0.07 (0.1)	0.19 (0.07)	0.3 (0.05)	0.110.08)

4. Discussion

The combination of fire-specific and vegetation indices identified the burned areas and their extend, providing insight into burn severity and allowing for post-fire assessments of vegetation recovery. When vegetation is affected by fire, there is a severe reduction in NIR reflection associated with an increase in the SWIR reflectance, allowing the identification of burned regions in a variety of forest ecosystems [21]. We found that the most accurate spectral index for mapping burned areas, demonstrating high discrimination ability of burn severity levels, was the difference form of NBR, the dNBR. Several studies have indicated that mapping accuracy is higher when using pre- and post-fire satellite images to calculate the difference in the NBR index [6,22]. NBR index is more sensitive to changes in chlorophyll and vegetation water content due to the inclusion of the NIR spectral band in its calculation [9,23]. This spectral band is particularly effective at identifying fire-affected areas since chlorophyll strongly reflects sunlight at NIR wavelengths, and vegetation damage or its absence makes the reflection low or non-existent [6]. NBR is particularly useful for detecting the difference between burned and unburned areas because it capitalizes on the increased

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reflectance of the SWIR in burned areas and the reduction of NIR reflectance in areas of vegetation loss [22,24]. We observed a much higher accuracy in mapping the extent of burned areas and burn severity when using dNBR over the $dNBR_2$ index, indicating the NBR efficacy in mapping fire-affected forest areas as found previously [25]. The SWIR spectral bands employed in calculating $dNBR_2$ are particularly sensitive to vegetation moisture content, identifying fire-affected areas due to the extreme drop in moisture levels [7]. However, moisture content is affected by variations in meteorological conditions, leading to inaccuracies and ambiguities among burn severity levels as found in this study [26].

Vegetation indices NDVI and EVI were useful in capturing vegetation loss and regeneration after the wildfire. Both indices showed reduction in photosynthetic activity of vegetation linked to a reduction in vegetation reflectance in the NIR spectral band due to the consumption of vegetation (chlorophyll) by wildfire, leaving the soil relatively bare. It is widely accepted that NDVI measures vegetation greenness, and is related to vegetation growth, coverage, productivity, and the structural properties of plants [22,27,28]. In the subsequent growing season, understory vegetation quickly regained photosynthetic activity with a large proportion of pixels returning to pre-fire levels within one year. This was also evident in heavily burned parts of the study sites showing an increase in photosynthetic activity of herbaceous vegetation and shrubs during the early stages of recovery. Vegetation recovery was successfully tracked as well by the EVI index due to its enhanced ability to identify vegetation properties by adjusting for signal saturation and reducing atmospheric disturbance [11]. However, *P. halepensis* trees did not demonstrate strong post-fire recovery capability, suggesting low resilience to wildfire occurrence enhanced by climate change stressors. Therefore, it is unlikely that this species will recover in the short term within the study area. Consequently, reforestation measures combined with fuel management and climate adaptation are essential to prevent further degradation in *P. halepensis* ecosystems. The integration of advanced remote sensing techniques for mapping burned area severity and assessing vegetation regeneration across various ecosystems holds significant implications for wildfire management in Albania. The spatial and temporal variability in burn severity can provide crucial insights into the expected recovery trajectories of affected ecosystems, enabling appropriate management responses [29,30]. Previous research conducted in the National Park “Dajti Mountain” in Albania showed promising results for mapping burned areas and evaluating regrowth dynamics in Mediterranean ecosystems [3]. Albania, characterised by its Mediterranean climate and diverse ecosystems, faces increasing threats posed by wildfires, requiring a robust management framework that incorporates remote sensing technologies for effective decision-making. Such technologies assist forest managers in adapting intervention strategies effectively [31,32].

5. Conclusion

This study applied a Remote Sensing and GIS approach to assess the fire-affected areas at two forest sites located in southern Albania. The integration of dNBR and vegetation indices enabled the precise mapping of burned areas, the assessment of burn severity, and the tracking of post-fire recovery at the study sites. The use of fire-specific and vegetation indices is therefore essential for identifying the impact of fires on various forest types in Albania. Such information could enhance forest management practices on fire-affected forest areas as the frequency and intensity of forest fires are expected to increase in response to changing climatic conditions. At both sites, it is recommended to implement reforestation measures for the restoration of *P. halepensis* forest. By enhancing our understanding of burn severity and vegetation recovery dynamics, this work supports more informed decision-making in forest management, climate resilience planning, and biodiversity conservation.

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