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Application of Remote Sensing and GIS techniques for detecting burned areas and severity. A case study of the National Park "Dajti Mountain", Albania

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Keywords
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ABSTRACT

Assessment of forest areas affected by wildfire is crucial for designing appropriate management strategies to support post-wildfire restoration. This study integrates Remote Sensing and GIS data to map burned areas and severity, and regeneration of vegetation in a Mediterranean forest type ecosystem (National Park "Dajti Mountain", NPDM), in Albania. Landsat 8 satellite imagery was employed to calculate various spectral indices such as the Normal Burn Ratio Index (NBR), NBR2, the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI). Burn severity levels were defined by using the dNBR thresholds developed by Key and Benson (2006). The accuracy of burn severity map produced was evaluated by relating field-based Composite Burn Index (CBI) and satellite-derived metrics (dNBR) from Landsat-8. By means of dNBR and dNBR2 we detected and mapped several burned forest areas within the NPDM, at the sites of Shkallë, Qafëmolle, Ibë, Tujan, Derje, Selbë, Surrel and Dajt, which were affected by wildfire during the year 2017. The dNBR produced the best results for burned areas mapping and burn severity assessment (91.7%) over the dNBR2 (89.8%). The dNBR and dNBR2 index maps showed that a total of 103.59 and 105.72 hectares of forests was affected by wildfire. Areas with different levels of burn severity were detected: 17.29 and 23.80% unburned, 43.36 and 45% low, 15.11 and 12.13% moderate, 24.93 and 21.2% high. Overall, the dNBR2 index produced lower percentages of wildfire-affected areas at high and moderate rates compared to the dNBR index while for unburned areas the dNBR2 index resulted in higher percentages. Vegetation recovery during the subsequent growing season was generally good as revealed by the high dNDVI and dEVI values, indicating the reactivation of photosynthetic activity. This information is useful for forest managers/specialists to design relevant strategies for the proper rehabilitation/management of burned forest areas in the future.

1. INTRODUCTION

Wildfire is considered any non-structured fire, other than prescribed fire, that occurs in the wildland (Firewise, 1998). Wildfires worldwide are affecting large areas and consequently are associated with negative impacts on forest ecosystems, such as: desertification, soil erosion, loss of water supply, biodiversity, biological functions which follow with large socio-economic losses, contribute to deforestation, greenhouse gas emissions, and also harm human well-being (Mallinis et al., 2018). The increasing frequency and intensity of wildfires has led to an increase in the need to monitor them but also to assess areas damaged by wildfire through modern techniques including mapping with Remote Sensing and GIS methods. Satellite images have been used to detect changes in vegetation response to light spectrum in different spectral bands where these changes are reflected (Warner et al., 2017). Data provided by satellite images are very important for natural resource managers to understand and evaluate the effects of wildfires on the ecosystem as well as the impact of environmental changes on the ecological functioning of the ecosystem (Morgan et al., 2014). Accurate and rapid mapping of burned areas is essential to support their management

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/rehabilitation, to calculate environmental damage, to define planning/management strategies and to monitor vegetation regeneration. Given the time and field efforts of wildfire management as well as the permanent and temporary impacts that fire cause on the ecosystem, Remote Sensing has become a reliable and applicable alternative for assessing the extent of wildfires (Lentile et al., 2006).

The most widely used method for evaluating wildfire impacts in the field is the Composite Burn Index (CBI) developed by Key and Benson, (2006). This field protocol, has shown good correlation with the spectral reflectance recorded from remote sensing images (Key and Benson, 2006; Mallinis et al., 2018). Several methods have been developed for mapping wildfire-affected areas from multi-temporal or single post-wildfire satellite images (Hudak et al., 2007; Escuin et al., 2008). These methods comprise a variety of spectral indices (e.g., NDVI, EVI, NBR, NBR2, MIRBI, BIAS2, BAI, etc.) covering the visible/NIR, the NIR/short SWIR and the short SWIR/long SWIR spectral spaces (Hu et al., 2021; Sirin and Medvedeva, 2022). However, the Normalized Burn Ratio difference (dNBR, dNBR2) and the Normalized Difference Vegetation Index (NDVI) have shown a good correlation with wildfire severity and therefore have been widely used for estimating burn severity and vegetation regeneration (Key and Benson, 2006; Mallinis et al., 2018; Atak and Tonyaloğlu, 2020). The ability of dNBR index to differentiate wildfire effects on vegetation is strongly related to the contrasting signal in NIR and SWIR reflectance bands provided by healthy versus wildfire-disturbed vegetation (Saulino et al., 2020). Remote sensing burn severity indices are able to rapidly and accurately detect burned forest areas which is crucial for post-wildfire management practices, especially in spatial heterogeneous and prone to wildfire Mediterranean forest ecosystems. During the year 2017, in several Mediterranean countries large forest areas were affected by wildfires (San-Miguel-Ayanz et al., 2018). This is also the case of Albania where in 2017 have been reported many wildfires all over the country. These wildfires occurred repeatedly, mostly on shrublands and less in high forests. In most cases, causes of forest fires remain unknown but it is believed that they are human set wildfires. Apart from many shrub species, considerable areas of *Pinus nigra* and *Fagus sylvatica* forests were burned all over the country causing high economic and ecological damage (Forestry Sector Study Report, 2021).

The aim of this study was to evaluate the environmental impacts of wildfires that occurred during year 2017 in national park "Dajti mountain" (NPDM), region of Tirana, Albania, by means of Remote Sensing and GIS data. More specifically, it was intended to assess forest areas affected by wildfire, evaluate burn severity and the current state of vegetation (regeneration) in the affected areas. The objectives of this study were: (1) to produce burned area and severity maps of National Park "Dajti Mountain" by means of dNBR and dNBR2 indices and assess their accuracy, (2) to identify the most capable spectral index for evaluating wildfire severity and vegetation regeneration, (3) to evaluate the current state of vegetation (regeneration) in affected areas through the use of NDVI and EVI vegetation indices maps.

2. METHOD

2.1. Study Area

Study area is located about 5 km North-East of Tirana and covers the entire territory of National Park "Dajti Mountain" (NPDM) as well as areas around it (Figure 1). NPDM is affected by the Mediterranean pre-mountain and mountain climate characterized by relatively cold and humid autumn and winter while spring and summer are drier and hotter.

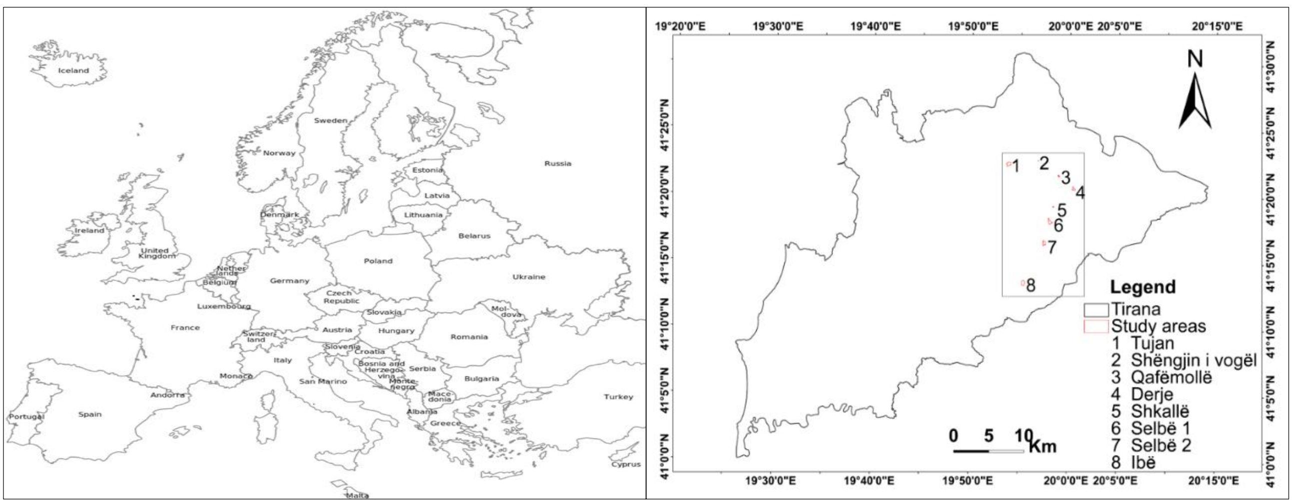

Figure 1. Map of Europe (left) and the study area located in north-east of Tirana (right). Red perimeter delineate the burned areas located within the national park "Dajti Mountain

Average annual temperatures range from 15°C to 22°C. Nearly 70% of the annual precipitation falls in winter where the maximum rainfall reaches up to 237 mm per day (Bruci, 2007). The elevation ranges between 650m and 1613m, whereas the slope varies between 5% -70%. The park is characterized by fragmented and rugged topography which creates favorable conditions for a great diversity of ecosystems. Generally, NPDM is dominated by grey dark soils which are distributed at altitudes of 900-1600 m above sea level, but also by brown soils up to 900 m. The vegetation is characterized by evergreen species such as *Arbutus unedo*, *Erica arborea* and *Quercus ilex* and deciduous species such as *Fagus sylvatica*, *Quercus frainetto*, *Quercus cerris*, etc, and shrubs *Carpinus orientalis*, *Corylus avellana*, etc. NPDM is fire prone area where wildfires are occurring frequently every year. In particular, the year 2017 was characterized by extensive burning at the NPDM, including large and small burned areas with different levels of burn severity. Most wildfires occur during the dry season, from June to August, when vegetation contributes to accumulation of dry fuels that are easily combustible (Forestry Sector Study Report, 2021).

2.2. Field Data Collection

One month after the wildfires, a total of 30 Composite Burn Index CBI plots (30m × 30m) were established randomly within the wildfire affected areas. Wildfire severity was evaluated visually and classified at four levels of burn severity (unburned, low, moderate and high). Geographical coordinates were recorded at the center point of each plot using a GPS and digital photos were taken (See appendix 1). The four strata identified were substrate, herbs, shrubs and trees. They were stratified according to the forest type of the area combined with a preliminary interpretation of satellite image. Wildfire severity for each strata was visually evaluated as described in CBI data sheet (Key and Benson, 2006). The CBI contains information to evaluate burn severity level for five main strata of the vegetation: substrate, vegetation (herbs, shrubs, and trees) less than 1 m tall, tall shrubs and trees 1–5 m, intermediate trees (sub-canopy and pole-sized trees) and big trees (canopy, dominant and co-dominant) (Key and Benson, 2006). Burn-severity level within each stratum is estimated on a 0.0–3.0 scale. CBI overall severity value was then calculated by averaging the strata values of each plot. Field data of burned areas and severity were used to validate results (accuracy assessment) produced by Remote Sensing Landsat 8 spectral indices.

2.3. Satellite Data Collection and Analysis

To assess the forest areas affected by wildfires, a combination of satellite and field data were used. Cloud-free Landsat 8 satellite images acquired pre and post fire (June – August 2017, respectively) were used in the analyses. Landsat 8 satellite imagery was downloaded free of charge on the US Space Agency (NASA) website (Url-1). Table 1 lists the band names, spatial resolutions and wavelengths of Landsat 8 OLI sensor.

Table 1. Spectral bands characteristics of Landsat 8 OLI

Bands	Wavelength (micrometers)	Resolution (meters)
Band 1 - Coastal aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3 - Green	0.53-0.59	30
Band 4 - Red	0.64-0.67	30
Band 5 - Near Infrared (NIR)	0.85-0.88	30
Band 6 - SWIR 1	1.57-1.65	30
Band 7 - SWIR 2	2.11-2.29	30
Band 8 - Panchromatic	0.50-0.68	15
Band 9 - Cirrus	1.36-1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.6-11.19	100
Band 11 - Thermal Infrared (TIRS) 2	11.50-12.51	100

The study area encompasses UTM zones 34, north. Images were downloaded in Level-2C product format and had some pre-processing related to geometric and radiometric correction based on field control points and the Digital Elevation Model (DEM) for topographic accuracy. The reflectance images were then imported into Miramon software for further analysis. The images were projected to the UTM/WGS84 projection. The pre-wildfire and post-wildfire images were selected as close as possible to the wildfire occurrence, in order to minimize spectral differences due to seasonal changes in the landscape. The eight wildfires considered in this study occurred during the time interval 14 July-18 August of year 2017. The pre-fire image (LC08_L1TP_186031_20170601) was selected on the 01th of June 2017 and the post-fire image (LC08_L1TP_186031_20170820) was selected on the 20th of August 2017. Landsat 8 satellite images were used to calculate spectral indices for burned area and severity assessment, as well as for vegetation regeneration. Spectral indices employed in this study were the Normalized Burn Ratio (NBR), NBR2, Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) (Table 2). The pre-wildfire and post-wildfire NBR, NBR2 were used to calculate the differentiated NBR. The dNBR and dNBR2 index values were classified into several classes of burned severity (Table 3) following (Key and Benson, 2006).

Table 2. Spectral indices used in this study

Index full name	Abreviation	Formula	Reference
The Normalized Burn Ratio	NBR	(NIR – SWIR2) / (NIR + SWIR2)	Key and Benson, 2006
Differentiated NBR	dNBR	NBR_{pre} - NBR_{post}	Key and Benson, 2006
The Normalized Burn Ratio 2	NBR2	(SWIR1 – SWIR2) / (SWIR1 + SWIR2)	USGS, 2019
Normalized Difference Vegetation Index	NDVI	(NIR - RED) / (NIR + RED)	Tucker, 1979
Enhanced Vegetation Index	EVI	2.5*(NIR-RED)/(NIR+6RED-7.5BLU+1)	Huete et al., 2002

For Landsat 8: RED (Band 4); BLUE (Band2); NIR: Near infrared (Band 5); SWIR1: Short wave infrared (Band 6); SWIR2: Short wave infrared (Band 7)

Table 3. Classification of dNBR, dNBR2 values into burn severity classes (Key and Benson, 2006)

Burn severity class	Range of dNBR, dNBR2
Unburned	< 0.1
Low	0.1-0.349
Moderate	0.35-0.459
High	>0.46

To analyze and assess the current condition /regeneration of forest areas damaged by wildfire we used NDVI and EVI vegetation indices calculated on Landsat 8 images. In particular, near post (20th of August 2017) and one-year post fire (04th of June 2017) NDVI and EVI images were analyzed and difference images were used. The EVI index was used as a complement to the NDVI index because it was created to improve the vegetation signal and to provide more accurate data on photosynthetic activity on dense biomass areas (Huete et al., 2002).

2.4. GIS Analysis

The image maps of areas affected by wildfire and vegetation regeneration were imported to GIS where initially were converted to shapefile to calculate the respective areas. Moreover, based on the field data and the dNBR values we identified 8 forest sites within the DMNP affected by the 2017 wildfire which were located near the villages of Tujan, Shëngjin i Vogël, Qafë Mollë, Derje, Shkallë, Selbe (2 areas) and Ibë (Figure 1). The perimeter of damaged areas was digitized and they were clipped on the dNBR and dNBR2 as well as the NDVI and EVI maps. Also, the preparation, comparison and export of maps produced was done through the use of Arc Map program.

3. RESULTS AND DISCUSSION

3.1. Burn area and severity

The fire-affected forest area evaluated in the field was 95 hectares (See appendix 2), whereas the one mapped by the Landsat spectral indices dNBR and dNBR2 were 103.59 and 105.72 ha, respectively (Table 4). Spectral indices clearly differentiated burned from unburned areas with a discrepancy of only 2% (Figure 2). Overall accuracies of forest burned area and severity maps generated with dNBR and dNBR2 were 91.7% and 89.8%, respectively.

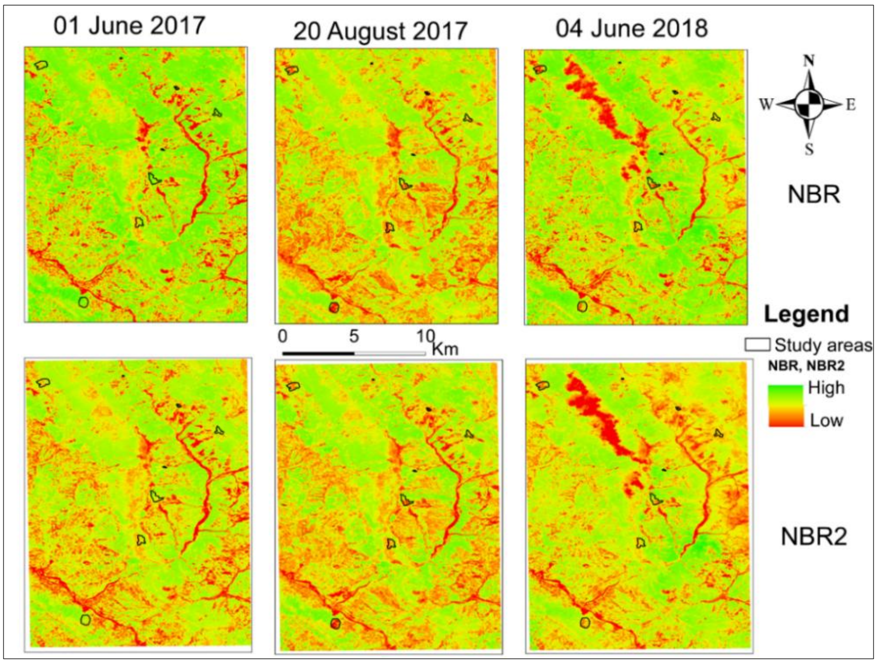

Figure 2. NBR and NBR2 images of the study area before the fire (01 June 2017), near after fire (20 August 2017) and after fire (04 June 2018). See Key and Benson, (2006) for NBR responses. Other details as in figure 1.

This indicates that dNBR spectral index was slightly more accurate at estimating fire severity compared to dNBR2. Various studies showed higher capability of NBR and NBR2 at discriminating burned areas as compared to other spectral indices (Sacramento et al., 2020; Sirin and Medvedeva, 2022; Atak and Tonyaloğlu, 2020). Based on these studies, both NBR and NBR2 indices produce similar results and are considered the most important indices to be used for burn area detection and mapping. However, the slight differences observed between NBR and NBR2 in this study could be related to NIR and SWIR spectral bands sensitivity to the characteristics of vegetation types in terms of density and spatial heterogeneity as they are captured from the remote sensing spectral reflectance (Mallinis et al., 2018). Figure 3 shows the forest areas affected by wildfire in 2017 at the NPDM, based on the dNBR/dNBR2 indices.

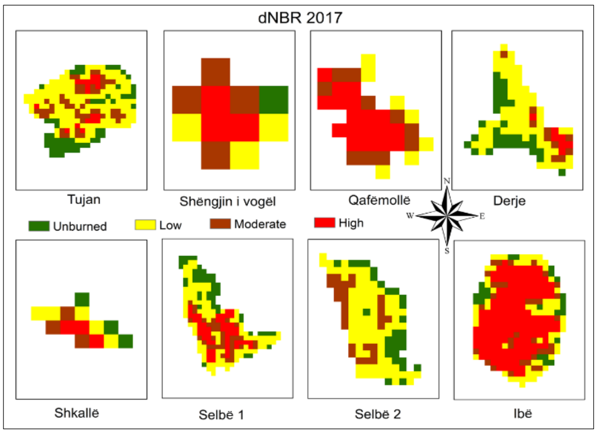

Figure 3. Maps of burned areas and burn severity detected by dNBR index

Forest site located at Ibë has suffered high wildfire damage as a significant part of the area was characterized by high dNBR values. More specifically, at Ibë about 60% of the forest area affected by wildfires was characterized by high burn severity while approximately 32% of the area was presented with moderate to low burn severity, and only 8% of the area was undamaged by wildfire (Figure 3, Table 4). Qafëmollë burned forest area also was characterized by high wildfire damage (51.42%), while in other forest areas (Shëngjin i Vogël (27.27%), Shkallë (21.43%), Selbe 2 (21.6%), Tujan (6.78%), Derje (5.83%)) only a relatively small part was characterized by high burn severity. Relatively high percentages of forest area moderately affected by wildfire were found at Shëngjin i Vogël (36.36%) and Qafëmollë (28.57%), while the areas with low burn severity were mainly found at Tujan (54.28%), Derje (58.33%), Selbe 1 (59.72%) and Selbe 2 (44.50%). Forest areas with the highest percentage of vegetation undamaged by wildfire were Tujan (21.07%), Derje (27.5%), Shkallë (21.43%) and Selbe 1 (20.14%). These tendencies are clearly observed in Figure 3 where the burn severity levels are visible through the respective colors.

Figure 4 shows the forest areas affected by wildfire in 2017 according to the dNBR2 index. Also with dNBR2 index it was possible to map the burned areas as well as discriminate different burn severity levels. High burn severity was found at the forest sites of Ibe, Qafëmollë and Selbe 2, while the areas characterized by low burn severity or undamaged by wildfire were found mainly at sites of Tujan, Derje and Selbe 1.

The similarities of dNBR2 with dNBR index in terms of damaged area assessment were high but still noticeable changes were observed in all categories of burn severity at all sites (Table 4).

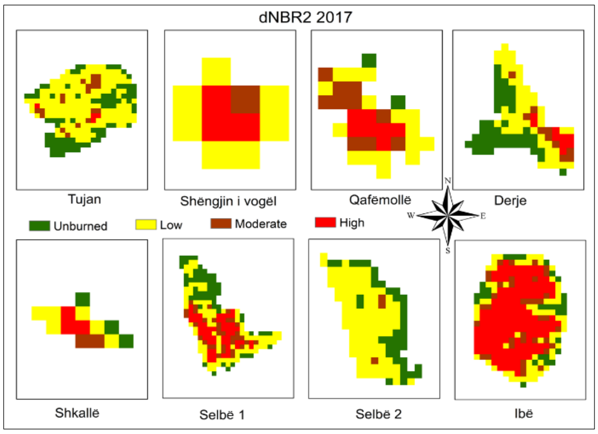

Figure 4. Maps of burned areas and burn severity detected by dNBR2 index.

Numerous researchers have studied the association between the dNBR index and wildfire severity all over the world to discriminate burned areas and assess vegetation regeneration after wildfire damage (Key and Benson, 2006; Nasery and Kalkan, 2020; Brown et al., 2018). They have found that the dNBR index achieves better discrimination of burned areas compared to other spectral indices due to the inclusion of near-infrared spectral band in its calculation. This spectral band is quite effective at discriminating areas affected by wildfire as chlorophyll strongly reflects sunlight at this wavelength and the scarce/lack of vegetation causes the reflection to be low/inexistent. When an area is burned, a drastic reduction in near-infrared reflection is observed, accompanied by an increase in the reflectance of the mid-infrared spectrum of most satellites (Lentile et al., 2006; Atak and Tonyaloğlu, 2020; Hu et al., 2021). Changes in spectral reflection of vegetation that occur after wildfire can be a good alternative for identifying patterns of areas affected by wildfire. The SWIR spectral bands used in the dNBR2 calculation are quite sensitive in terms of vegetation moisture content by identifying areas affected by wildfire due to their drastic drop in humidity level (Mallinis et al., 2018; Sacramento et al., 2020).

Table 4. Forest areas affected by wildfires in 2017 at the NPDM and the respective burn severity levels

Sites	Area (Ha)	Burn severity															
		Unburned				Low				Moderate				High			
		dNBR		$dNBR_2$		dNBR		$dNBR_2$		dNBR		$dNBR_2$		dNBR		$dNBR_2$	
		Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%
1	25.2	5.3	21.1	7.7	30.4	13.7	54.3	15.4	61.1	4.5	17.9	1.8	7.1	1.7	6.8	0.4	1.4
2	1.0	0.1	9.1	0.1	9.1	0.3	27.3	0.5	54.5	0.4	36.4	0.2	18.2	0.3	27.3	0.2	18.2
3	3.2	-	-	0.2	5.7	0.6	20.0	1.4	45.7	0.9	28.6	0.9	28.6	1.6	51.4	0.6	20.0
4	10.1	3.0	27.5	4.4	40.8	6.3	58.3	4.7	43.3	0.9	8.3	1.0	9.2	0.6	5.8	0.7	6.7
5	1.3	0.3	21.4	0.3	21.4	0.5	35.7	0.5	42.9	0.3	21.4	0.2	14.3	0.3	21.4	0.3	21.4
6	13.0	2.6	20.1	3.5	27.1	7.7	59.7	9.2	70.8	2.6	20.1	0.3	2.1	-	-	-	-
7	22.5	4.5	20.0	5.8	25.6	10.0	44.5	8.6	38.0	3.2	14.0	3.4	15.2	4.9	21.6	4.8	21.2
8	27.5	2.2	7.9	2.8	10.2	5.9	21.3	6.3	23.0	3.0	10.8	3.3	12.1	16.5	60.0	15.0	54.8
Total	103.6	17.9	17.3	24.8	23.8	45.0	43.4	46.6	45.0	15.8	15.1	11.1	10.7	25.9	24.9	22.0	21.2

Sites as in Figure 1.

3.2. Post-fire vegetation regeneration

Vegetation at the study area was generally characterized by high photosynthetic activity before the wildfire occurrence in 2017 but after the wildfire there is a considerable decrease in the values of NDVI and EVI, respectively (Table 5). However, the dNDVI and dEVI images indicate the reactivation of photosynthetic activity /regeneration of vegetation in burned areas (Figure 5, Figure 6).

Table 5. Statistical parameters of NDVI and EVI within the burned areas

	NDVI				EVI			
	Pre	Post	Dif.	Next season	Pre	Post	Dif.	Next season
Min	0.46	0.26	-0.04	0.41	0.28	0.07	-0.01	0.21
Max	0.90	0.88	0.59	0.83	0.80	0.67	0.62	0.75
Mean	0.81	0.58	0.23	0.64	0.58	0.31	0.26	0.45
Std. dev.	0.07	0.15	0.14	0.09	0.09	0.13	0.12	0.10

As a matter of fact, the regeneration of vegetation appeared to be generally good in the subsequent years as the flora affected by fire mainly consists of shrub species which are characterized by high sprouting ability. The regeneration of vegetation was completely natural with no human interferences. The reduction of NDVI and EVI values immediately after the wildfire occurrence (Table 5) is related to the reduction of vegetation reflection in the near infrared spectral band due to the consumption of vegetation (chlorophyll) by wildfire, leaving the soil relatively bare.

In the case of Tujan forest area there exists moderate vegetation damage mainly at the central part where a more pronounced change is found in dNBR and dNBR2 values (Figure 3, 4). In the succeeding year there are moderate level of vegetation regeneration at this site as revealed by the dNDVI and dEVI images (Figure 5, Figure 6). The area affected by wildfire at Shëngjin i Vogël, shows a higher degree of damage at the central part. However, the dNDVI and dEVI maps show a high level of vegetation restoration. In the forest area of Qafëmollë, regeneration of vegetation is evident in both dNDVI and dEVI indices and is observed mainly in the western and northwestern part of the affected area. In Derje forest area there is low impact of wildfire on vegetation and low changes regarding vegetation regeneration were observed in this area. Both vegetation indices showed the same pattern, although in the case of dNDVI the values obtained were higher. In the forest area of Shkallë vegetation was considerably regenerated after wildfire, as high values of vegetation indices (mainly dNDVI) were observed. At Selbe forest area we found 2 sites affected by wildfires in 2017. At Selbe 1 in the succeeding year there was observed low regeneration of vegetation as the largest part of the affected area was characterized by low values of dNDVI and particularly dEVI. At Selbe 2 it was observed low impact of wildfire on vegetation and consequently low regeneration in the subsequent year. The regeneration pattern showed some variation between dNDVI and dEVI at this site. At Ibë forest area the impact of wildfire on vegetation was quite high. In the following year there were found high values of dNDVI and dEVI meaning high vegetation regrowth. Such values were observed mainly in the central and southern parts of the area while the other parts showed relatively low values of vegetation regeneration.

Our findings are in line with previously published research which found NDVI and EVI useful to evaluate vegetation activity (Huete et al., 2002, Pasho and Alla, 2015). However, NDVI showed higher performance and provided more realistic results of forest regeneration as confirmed by the field observations.

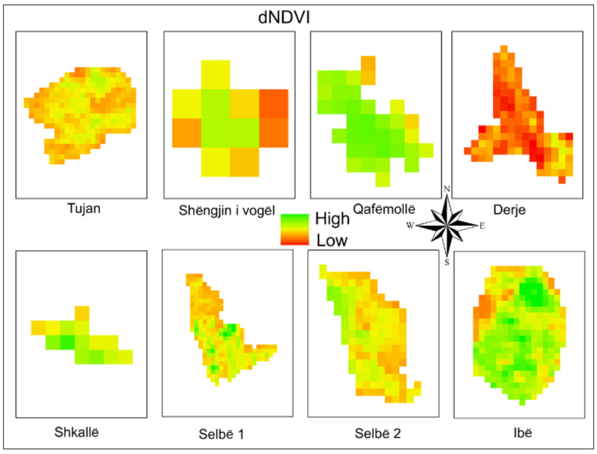

Figure 5. Spectral index maps showing the Normalized Difference Vegetation Index (dNDVI) of the burned areas in the subsequent growing season

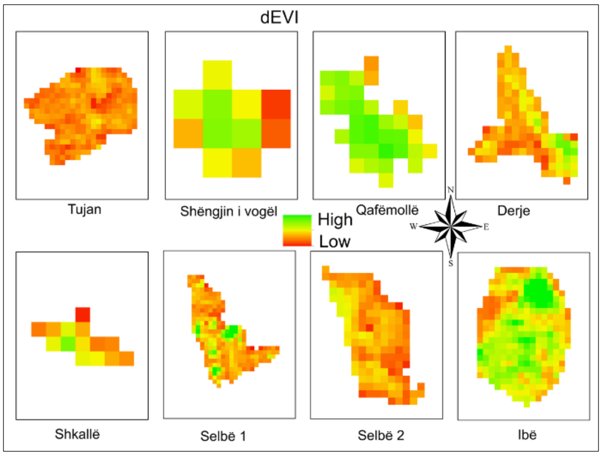

Figure 6. Spectral index maps showing the Enhanced Vegetation Index (EVI) of the burned areas in the subsequent growing season

4. CONCLUSIONS

In this research, burn severity maps were produced to spatially detect the forest areas damaged by multiple wildfires in 2017. The dNBR and dNBR2 burn indices obtained from the Landsat 8 OLI satellite were closely related to field CBI estimates of burn severity, demonstrating their potential use in mapping wildfire severity effects experienced by Mediterranean forest ecosystems. The study concluded that Landsat 8 spectral indices were efficient at discriminating burned from unburned areas as well as different levels of burned severity. The dNBR and dNDVI were the best indices to discriminate/delineate burned areas/burn severity and to evaluate vegetation regeneration in the subsequent season. While the combination of several alternative indices did not provide significant improvements in this study, they could prove useful in other areas but this is subject to further investigations. The burn severity varied from one area to another but it was particularly high at the forest areas of Ibë and Qafëmollë. The regeneration of vegetation in the succeeding year was poor at the forest areas of Derje and Tujan which were found to be low to moderately affected by wildfire while the areas highly affected by wildfires (Ibë and Qafëmollë) resulted to be in good state of vegetation regeneration in the following year. We recommend that in future studies, Remote Sensing and GIS technology be used widely for mapping and assessment of burned areas as an effective tool for forest managers/specialists in designing efficient management plans for the rehabilitation of these areas. In areas where the vegetation regeneration is low or absent, it is recommended to apply silvicultural measures (reforestation, afforestation, etc.) for their rehabilitation.

Author Contributions

Edmond Pasho: Conceptualization, Methodology, Software, Writing- Original draft preparation. **Arben-Q. Alla:** Data curation, Supervision, Writing-Reviewing and Editing. **Ernest Ramaj:** Data curation, Visualization.

Conflicts of Interest

The authors declare no conflict of interest.

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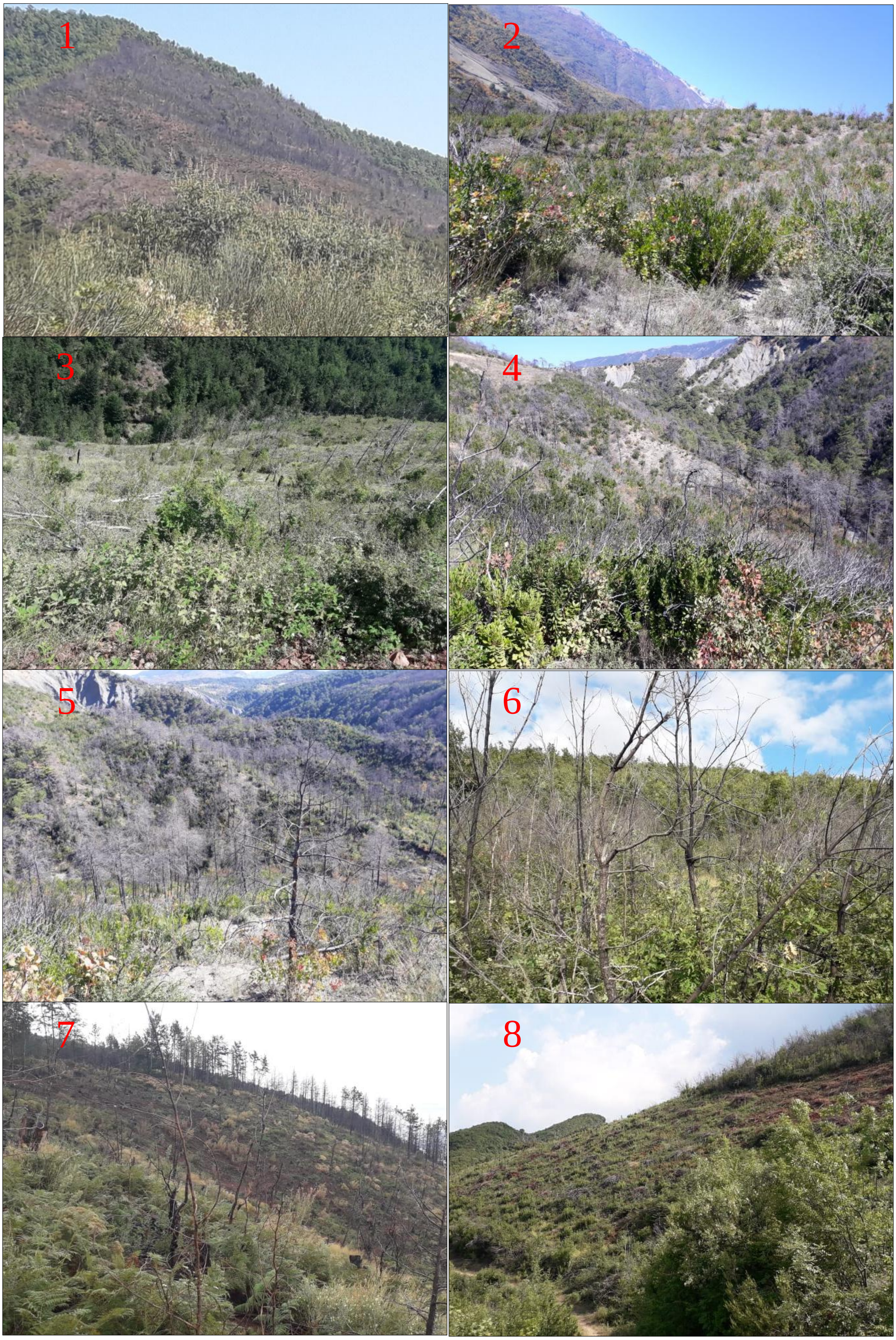
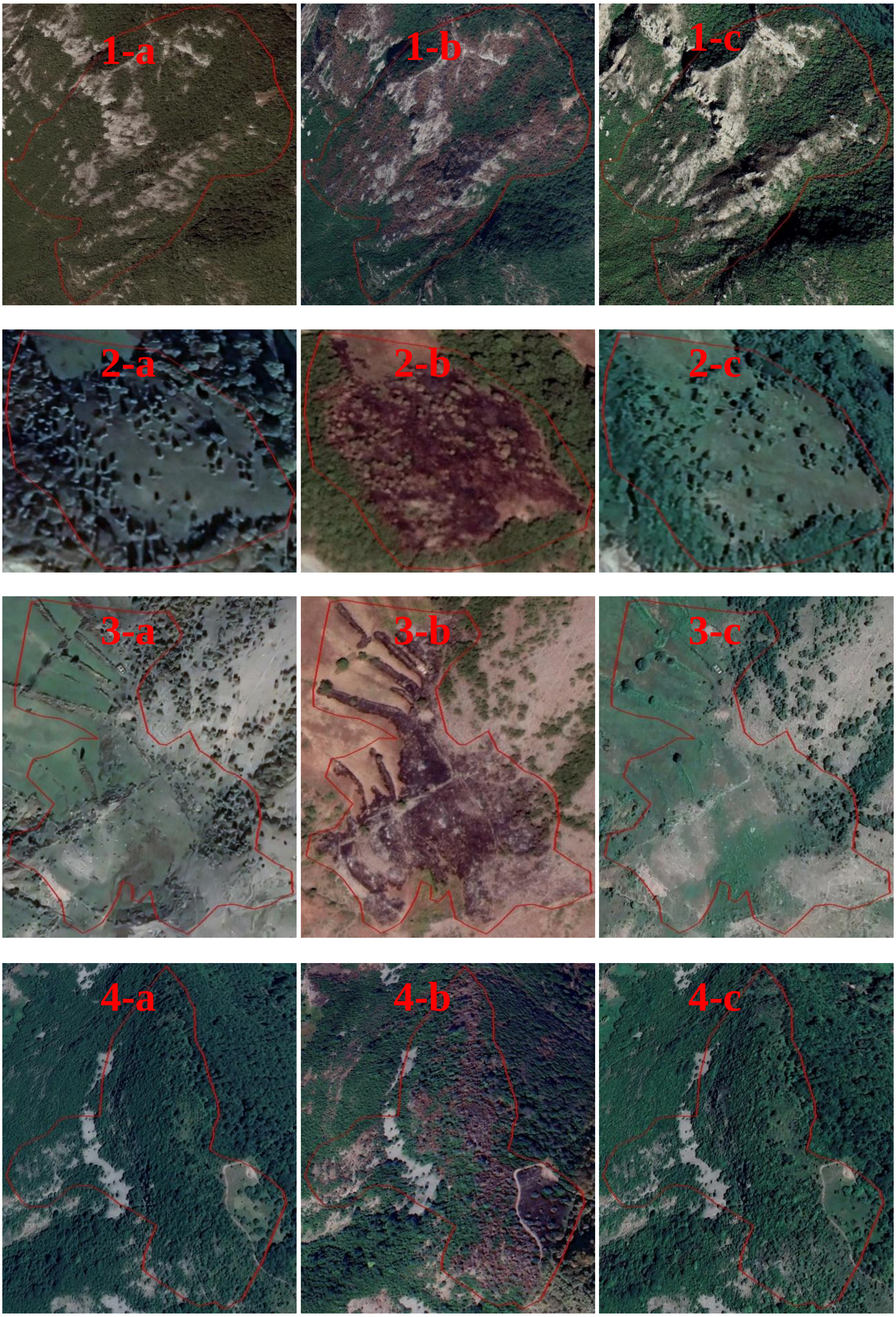
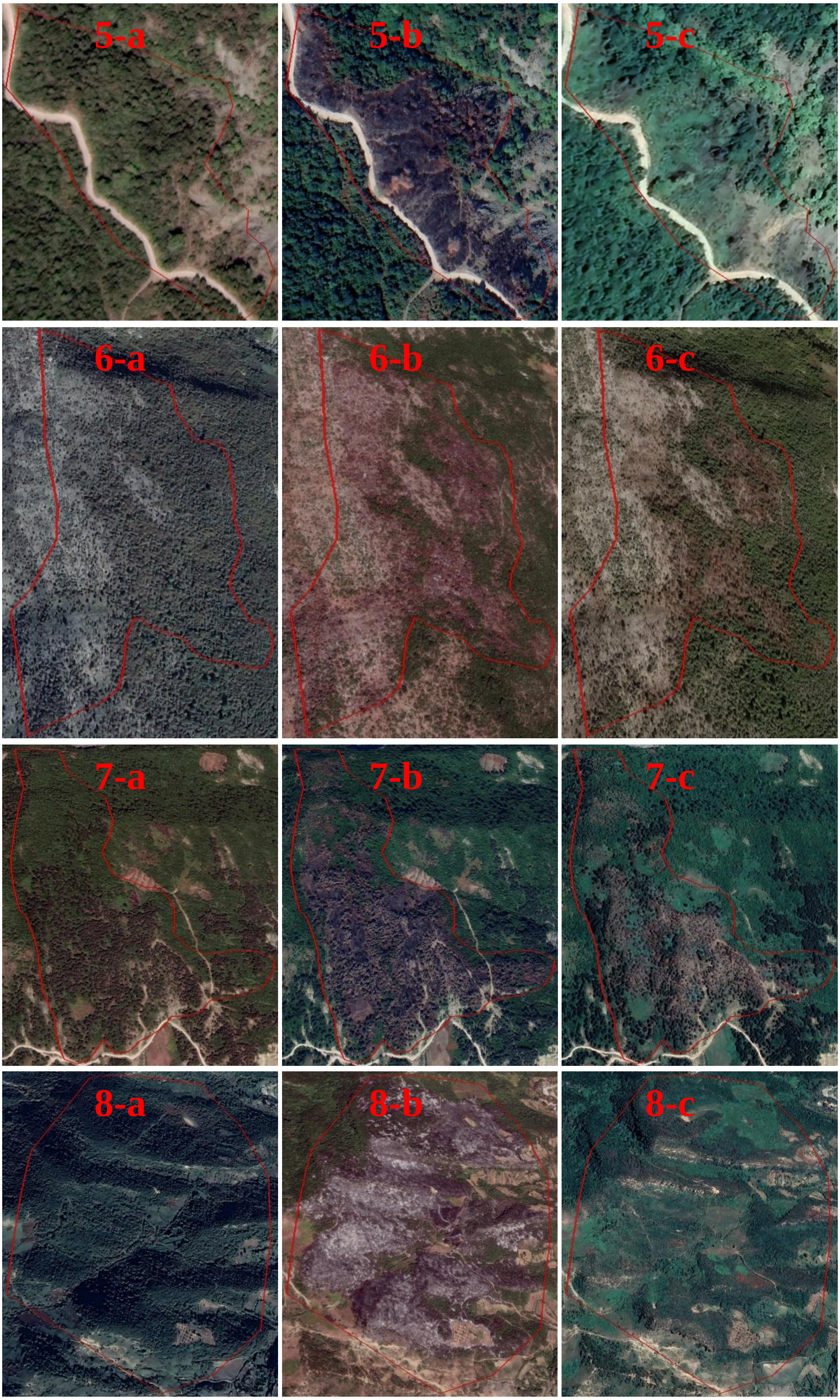
Appendix 1. Field photographs of post-fire conditions in the study area. Numbers as in Figure 1.



Appendix 2. Google earth images showing the study areas before the fire (a), near after the fire (b) and after the fire (c). Numbers as in Figure 1.




5-a
5-b
5-c
6-a
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7-b
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