The development of a Forest Canopy Density (FCD) model in Akamas National Forest Park in Cyprus, using Landsat-8 and Sentinel-2 satellite data

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Abstract The canopy of trees plays a very important role in forest ecosystems and acts as a regulator, affecting the microclimate and the soil conditions. The density of the forest canopy is associated to the forest development and it can be used as an indicator of forest degradation. Additionally, forest density is one of the most important parameters, used in the design and implementation of programs for forest restoration, especially in cases of areas affected by fires. The main objective of this study is to determine the disturbance that occurred in the canopy density of the Akamas National Forest Park in Cyprus after the fire that occurred on November 13rd, 2019. For the purposes of this study, the Forest Canopy Density model (FCD model) was estimated using the Landsat-8 satellite data. Moreover, this study aimed to evaluate the FCD using Sentinel-2 data. The results from the two satellite sensors were validated and compared with each other. The results obtained from Sentinel-2 seem to be very promising and the calculation of the canopy density through this study is achieved in a better resolution, in contrast to the analysis available by the Landsat-8 satellite.

Keywords: Forest Canopy Density, FCD model, Earth observation, Sentinel-2, Landsat-8.

1. Introduction

The canopy of trees plays a very important role in forest ecosystems and acts as a regulator, as it is a factor that affects the microclimate and the soil conditions. The density of the forest canopy is associated to the forest development and can be used as an indicator of forest degradation.. Additionally, forest density is one of the most important parameters, used in the design and implementation of programs for forest restoration, especially in cases of areas affected by fires.

Two important factors that affect the quantification of the canopy are: the determination of the canopy and the technique used to estimate the dome (*Korhonen et al., 2006, Abdollahnejad et al., 2017*).

For the purposes of this study, the Forest Canopy Density model (FCD model) was estimated in order to quantify the size of the disturbance that occurred in the canopy density of the Akamas National Forest Park in Cyprus after the fire that occurred on November 13rd, 2019. The FCD model is an affordable and less costly method and less time-consuming compared to other methods (Mon et al., 2012), and besides that, it provides very good accuracy (Deka et al., 2013).

2. Materials and Methods

2.1. Study Area

For the purposes of this study, the fire event in Akamas peninsula in Cyprus (the central coordinates: 35.050°N, 32.300°E) has been studied as shown in **Figure *1***. The Akamas Peninsula is located in the western part of Cyprus, in Paphos, and is one of the most important ecological areas of Cyprus rich in species and habitats and is part of the Natura 2000 network.

Figure 1 Fire detection on the 13-11-2019 at the Akamas National Park in Cyprus (Sentinel-2)

2.2. Materials

For the objectives of this study, we used a near-simultaneous Sentinel-2 MSI and Landsat 8-OLI images of the East Mediterranean region, containing Cyprus and the two areas of interest. Geometrically corrected Landsat 8-OLI surface reflectance images were downloaded from the United States Geological Survey – USGS (https://earthexplorer.usgs.gov/) and the Sentinel 2 -MSI images were downloaded from the Sentinels Scientific Data Hub (https://scihub.copernicus.eu/dhus/#/home). The dates of the selected images are shown in *Table 1*

Table 1 Acquizition dates of satellite data

Sentinel-2	Landsat-8 OLI
5/11/2019	8/11/2019
20/11/2019	24/11/2019

2.3. Methodology

In this study, the FCD of Akamas national Forest Park in Cyprus from Sentinel-2 satellite images is evaluated and at the same time compared with the results obtained from Landsat 8 satellite images. The available, cloud-free images before and after the fire event were retrieved. **Figure 2** shows the methodology followed.

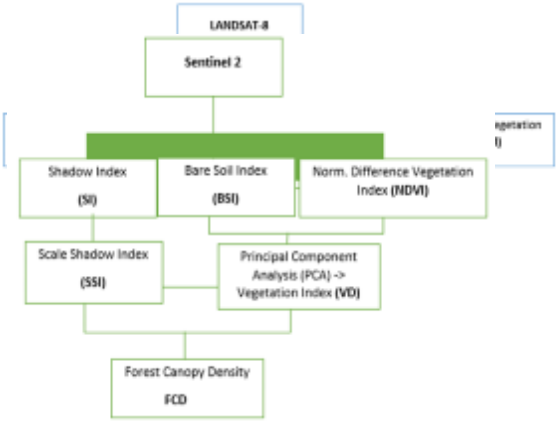

Figure 2: The diagram of methodology

FCD model is a combination of four biophysical indices which are NDVI, BSI, SI and TI. The calculation of the FCD is given from the Equation 1

Equation 1 Forest Canopy Density Model (FCD)

$$FCD = \sqrt{VD * SSI + 1} - 1$$

The Normalized Difference Vegetation Index **(NDVI)** is a widely used vegetation index computed from the combination of visible and near-infrared light reflected by vegetation Equation 2. Also, it is a very common index which is used to measure healthy vegetation and to highlight the burnt land (*Pinty and Verstraete, 1992*).This index is based on the high reflection of the green vegetation in the NIR spectral region and the radiation absorption by chlorophyll in the red spectral (*Schepers et al., 2014*).

Equation 2 Normalized Vegetation Index (NDVI)

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

BSI: The Bare Soil Index *Equation 3* helps to better distinguish bare soil from vegetation. The bare soil index has been calculated using Equation 2 (*Rikimaru et al., 2002*).

Equation 3 Bare Soi Index

$$BSI = \frac{(SWIR + RED) - (NIR + BLUE)}{(SWIR + RED) + (NIR + BLUE)}$$

SI: This index it helps to understand how dense are the trees because based on this index provides information about the arrangement of the treesSI has been calculated using Equation 4 (Abdollahnejad et al., 2017).

Equation 4 Shadow Index

$$SI = (1 - BLUE) * (1 - GREEN) * (1 - RED)$$

Thermal Index: Due to the shadow and presipitation of trees the temperatures differ between forest and non-forests areas and this is due to the perspiration of the trees and the shadow. The Land Surface Temperature was calculated using Equation 5.

Equation 5 Thermmal Index

$$L = L_{min} + \left(\frac{L_{max} - L_{min}}{255}\right) * Q$$

$$T = \frac{K_2}{Ln\left(\frac{K_1}{L} + 1\right)}$$

L: value of radiance in thermal infrared
T: ground temperature (k)
Q: pixel DN value
K_1, K_2: Calibration Coefficients
K1=774.8853, K2= 1321.0789

3. Results and Discussion

Forest canopy density was calculated for the Akamas National Park before and after the fire event which occurred on 13 of November in 2019. As mentioned above for the calculation of the FCD model the 4 spectral indices (NDVI, BSI, SI, and TI (only for Landsat-8)) were calculated (Sentinel-2 and Landsat-8) and based on these indices the FCD model was estimated for each satellite sensor.

In *Figure 3* and *Figure 4*, the results of the FCD are presented for each satellite data.

The values of the index were divided into 3 categories:

- Unvegetated -very low vegetation areas: 0-41% **(class 1)**
- Low -Middle forest: 41-70% **(class 3)**
- Dense – Very Dense forest: 71-100% **(class 4)**

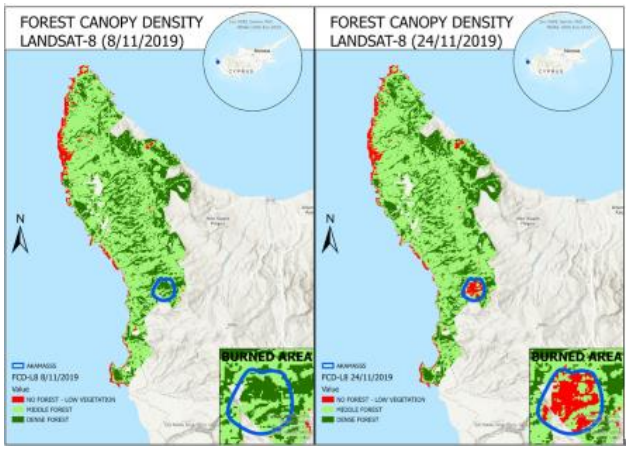

Figure 3 Forest Canopy Density (FCD) using Landsat-8 images a) Pre-fire, b) post-fire

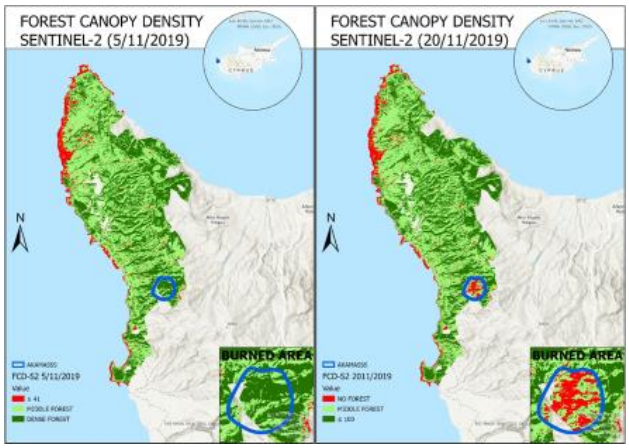

Figure 4 Forest Canopy Density (FCD) using Sentinel-2 images a) Pre-fire, b) post-fire

According to the CORINE Land Cover data, dense forest is characterized mainly by Coniferous Forest, the middle forest mainly by sclerophyllous vegetation and the unvegetated areas by beaches, dunes, and sands.

As mentioned above the FCD index for each satellite sensor was divided into 3 categories. For each class, were calculated the percent area firstly for the whole Akamas area Table *2* and secondly above the burned area

Table ***3***.

Table 2 Percentages for each class for Akamas area

	LANDSAT-8		SENTINEL-2	
	8/11/2019	24/11/2019	5/11/2019	20/11/2019
NO FOREST (%)	4.42	5.08	6.39	6.71
MIDDLE FOREST (%)	65.33	65.83	54.29	53.33
DENSE FOREST (%)	30.25	29.09	39.33	39.97

Table 3 Percentages for each class above the burned area

	LANDSAT-8		SENTINEL-2	
	08/11/2019	24/11/2019	05/11/2019	20/11/2019
NO FOREST (%)	0.00	58.28	0.15	46.50
MIDDLE FOREST (%)	50.54	40.72	33.71	48.28
DENSE FOREST (%)	49.46	1.00	66.14	5.23

According to the results for the burned area, it seems that the Landsat-8 and Sentinel-2 satellite before the occurrence of the fire for the class "no forest" the percent coverage was estimated at 0% and 0,15% respectively which means the area was characterized mainly by middle and dense forest. But after the fire event, the values of the "no forest" class from both satellite sensors were increased which is mean that the "middle forest" and "dense forest" were disturbed, and this is the reason where the values of these classes were changed as shown in the

Table ***3***. In summarize in both cases, the burned area's percentage of the class "no forest" increased (Figure 5), and the other classes fluctuated, respectively.

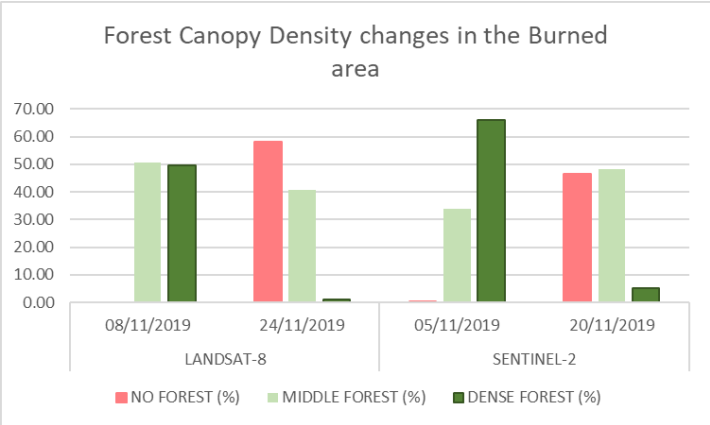

Figure 5 Forest Canopy Density changes in the burned area

In addition, in order to better estimate the relationship between the values of the three classes that derived from each satellite sensor, the correlation coefficient estimated. The values of the three classes over the Akamas area and above the burnt area were extracted for each satellite sensor to estimate the correlation coefficient with the Pearson method. The results are shown in Table 4. By comparison, the values of each class are greater than +0.70 and therefore they have a strong uphill (positive) linear correlation.

Table 4 Correlation Coefficient

	Correlation Coefficient for L8 and S2	
	Pre-fire	Post-fire

Akamas area	0.955	0.935
Burned area	0.862	0.943

4. Conclusions

FCD model is a combination of four biophysical indices which are NDVI, BSI, SI and TI .The FCD model has been used in several studies using mainly Landsat satellite data that have a thermal channel for the calculation of TI. However, in this study, it was attempted to estimate the FCD using Sentinel-2 data without the TI in order to map the damage caused from fire.
This model was useful for investigating the effects of fire on canopy density. The use of both satellite sensors (Landsat-8 and Sentinel-2) showed similar variations in canopy density changes. Through this study, the Sentinel-2 satellite showed very promising results for the estimation of FCD with better spatial resolution than Landsat 8.

As shown by the correlation coefficient analysis, the estimated values for the percent area covered by each class where obtained from each satellite image, showed a strong uphill-positive linear relationship. Based on this, in cases that a Spatio-temporal analysis is needed to study the forest canopy density changes and create a time series, the combination of Sentinel-2 and Landsat-8 images can be utilized.

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