MAPPING POST-FIRE VEGETATION RECOVERY AT DIFFERENT LITHOLOGIES OF TAYGETOS Mt (GREECE) WITH MULTI-TEMPORAL REMOTE SENSING DATA

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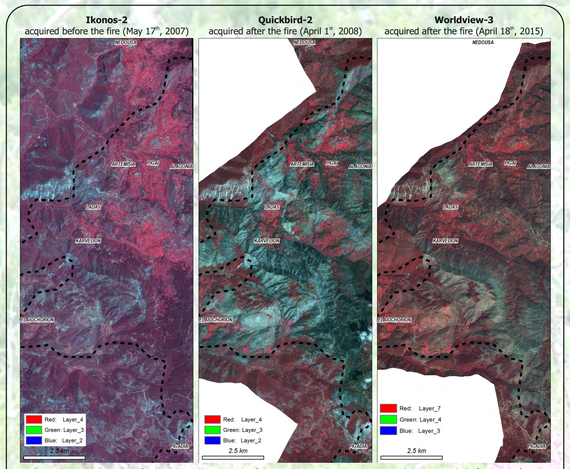


High resolution ortho-georeferenced satellite images of the study area, acquired at several time periods before and after the fire of August 1st, 2007, (the burned area is delineated by the dashed line). All three figures are pseudo-color images as the Red color is assigned tothe Infra-Red band and Green/Blue are assigned to bands at visible spectrum. Therefore, the vegetation is represented with red colors due to the high reflection properties of the chlorophyl at the infra-red area of the spectrum. Note the gray and green colors at the middle figure representing the burned forests, as well as the isolated reddish unburned forest stands in between.

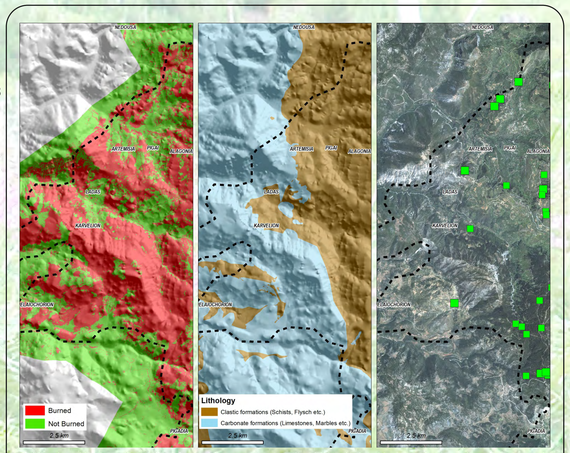
ABSTRACT

Taygetos Mt (2407m), located at southern Peloponnese (Greece) experienced a large fire during the summer of 2007. The fire burned approximately 45% of the area covered by the endemic Greek fir (*Abies cephalonica)* and Black Pine (*Pinus nigra*) forest ecosystems. The aim of the current study is to examine the potential differences on post-fire vegetation recovery imposed by the lithology as well as the geomorphology of the given area over sites of the same climatic and landscape conditions (elevation, aspect, slope etc.). The main lithologies consist of carbonate, permeable, not easily erodible formations (limestones and marbles) and clastic, impermeable (schists, slate and flysch) erodible ones.

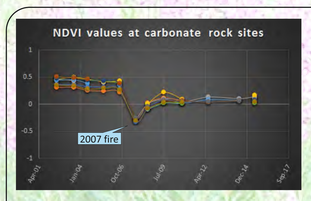
A time-series of high spatial resolution satellite images was interpreted, analyzed and compared in order to detect changes in vegetation coverage which could prioritize areas of interest for fieldwork campaigns. The remote sensing datasets were acquired before (**Ikonos-2**), a few months after (**Quickbird-2**) and some years after (**Worldview-3**) the 2007 fire. High resolution Digital Elevation Model was used for the ortho-rectification and co-registration of the remote sensing data, but also for the extraction of the mountainous landscape characteristics.

The multi-temporal image dataset was analyzed through GEographic-Object Based Image Analysis (GEOBIA). Objects corresponding to different vegetation types through time were identified through spectral and textural features. The classification results were combined with basic layers such as lithological outcrops, pre-fire vegetation, landscape morphology etc., supplementing a spatial geodatabase used for classifying burned areas with varying post-fire plant community recovery.

We validated the results of the classification during fieldwork and found that at a local scale, where the landscape features are quite similar, the bedrock type proves to be an important factor for vegetation recovery, as it clearly defines the soil generation along with its properties. Plant species recovery seems to be controlled by the local lithology as it was found weaker in plots overlying limestones and marbles, comparing to that observed over schists, even for the same species. In conclusion, post-fire vegetation recovery seems to be a complex process controlled not only from species biology, but also from the geological features.



Fieldwork and in-situ soil sampling along with vegetation sampling (right, depicted in green dots) was based on two main criteria:
(I) sites should be within the burned forested area, as this was mapped based on the NDVI calculated values of the analyzed Quickbird-2 image data (left).
(II) the outcrops of the lithological formations, which are observed on the Taygetos Mt. (middle). The formations were unified into two main units according to their properties.



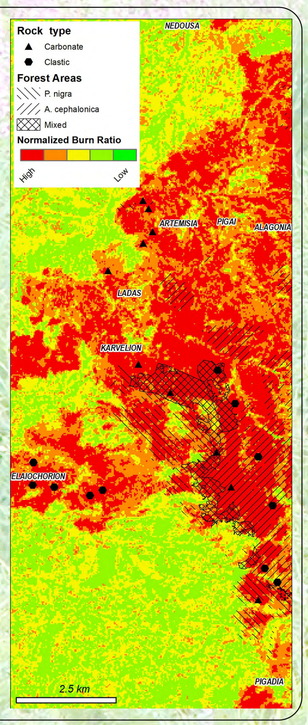
A total of 12 Landsat 5 and 7 ETM+ scenes for the path 184 and row 034 and time frame of 2002-2015, with minimal cloud cover during summer period were co-registered in a common projection system for the generation of a multi-temporal change detection dataset.

The satellite images were radiometrically and atmospherically corrected according to the most widely acceptable procedures. For every single geometrically and atmospherically corrected satellite image, the normalised difference vegetation index (NDVI) was calculated by using the red and infrared spectral bands.

The extracted NDVI index images for each time period were comparable spatially as well as quantitatively. As a result, a new 12-channel dataset was generated after stacking each years' NDVI calculation. Taking under consideration the 2007 burned area as well as the NODATA stripes of the Landsat 7 ETM + sensor failure after 2003, a number of randomly distributed sampling points were selected and at each point location, we calculated and compared the NDVI value. The sampling points were selected, by satisfying the following rules:

- location inside the perimeter of the 2007 burnt area
- high values of Normalized Burn Ratio (NBR) index (see right)
- dense forest areas

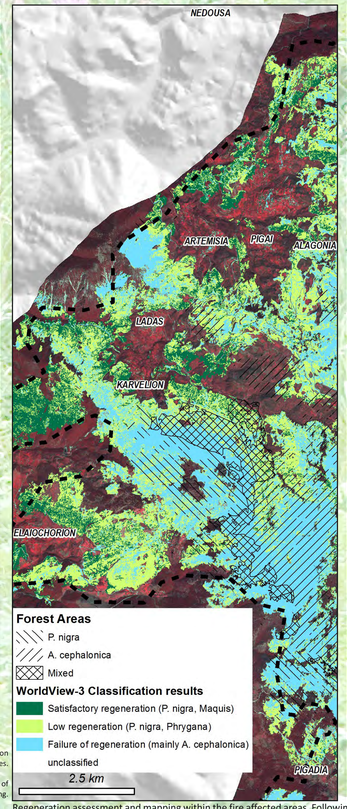
The results show that the clastic rocks (Schists, Flysch) recover much faster than the carbonate rocks (Limestones, Dolomite) by gaining the lost NDVI values.

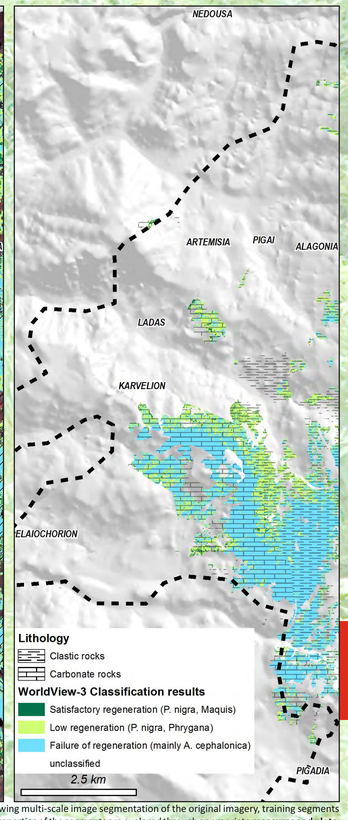


Failure of post-fire natural regeneration of Abies cephalonica, usually growing over limestone, despite the presence of unburned trees and stands.

Note the difference between the *Pinus nigra* forest recovery achieved in the the two different lithologies. The post-fire regenerating *Pinus nigra* recovers more rigorously when growing over schists producing higher plant cover and biomass as compared to its neighboring community overlying limestones.

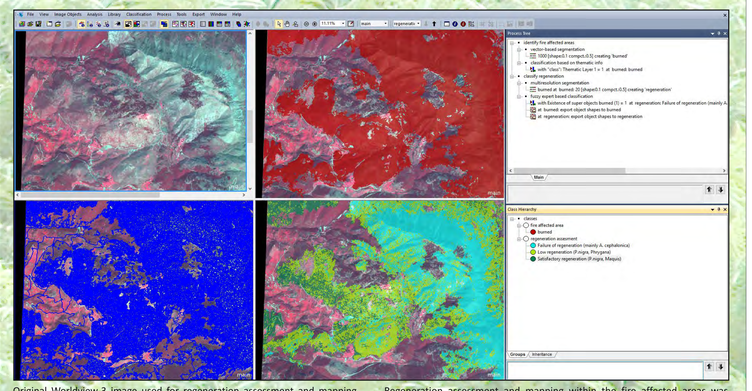
Successful regeneration and satisfactory recovery of *Pinus nigra* population over clastic lithologies.





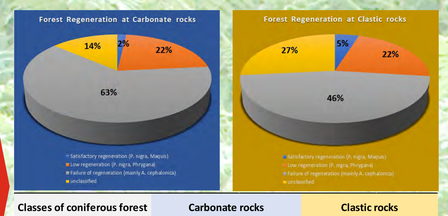
Regeneration assessment and mapping within the fire affected areas. Following multi-scale image segmentation of the original imagery, training segments were selected considering field plots location and characteristics. Spectral properties of the segments are explored through appropriate **measures and plots**. Finally, using expert knowledge, class membership functions are developed for each regeneration class to delineate the spatial explicit regeneration map.

The regeneration classes combined with the different types of forests (note the different types of hatch) which were burned during the 2007 fire event, are displayed at the left figure. The same forest areas along with the lithology surface properties are displayed at the right figure. Check the statistics next to it, where it is clear that the failure of regeneration is significantly higher at carbonate rocks as well as the satisfactory regeneration covers a much larger area at the clastic rocks outcrops.

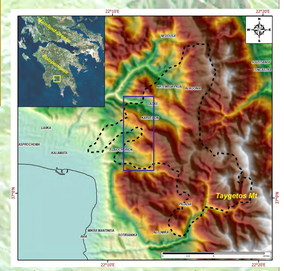


Original Worldview-3 image used for regeneration assessment and mapping (upper left), vector -based segmentation and classification of the burned area (red) extent using the 2008 Quickbird image (upper right), multi-resolution segmentation within the fire-affected area (lower left) and classification of the regeneration status within the same area using fuzzy membership functions (lower right).

Regeneration assessment and mapping within the fire affected areas was performed by following multi-scale image segmentation of the original imagery, training segments which were selected considering field sampling location and their characteristics. **Spectral properties of the segments are explored through appropriate measures and plots**. Finally, using expert knowledge, class membership functions were developed for each regeneration class to delineate the spatial explicit regeneration map.



Classes of coniferous forest regeneration	Carbonate rocks (limestone, dolomite)		Clastic rocks (schist, flysch)	
	Area (sq.km)	*percentage*	*Area (sq.km)*	*percentage*
Satisfactory regeneration *(P. nigra, Maquis)*	0.14818	2%	0.4746	5%
Low regeneration *(P. nigra, Phrygana)*	1.7652	22%	2.14321	22%
Failure of regeneration *(mainly A. cephalonica)*	5.11998	63%	4.50706	46%
unclassified	1.11383	14%	2.5849	27%



Relief map of the broader study area of Taygetos Mt. The dashed line surrounds the 2007 fire event. The inset map shows the location of the relief map at the Peloponnese peninsula (Southern Greece). The outline of all maps presented here is also displayed.

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