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Mapping post-fire forest regeneration and vegetation recovery using a combination of very high spatial resolution and hyperspectral satellite imagery

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ABSTRACT

Careful evaluation of forest regeneration and vegetation recovery after a fire event provides vital information useful in land management. The use of remotely sensed data is considered to be especially suitable for monitoring ecosystem dynamics after fire. The aim of this work was to map post-fire forest regeneration and vegetation recovery on the Mediterranean island of Thasos by using a combination of very high spatial (VHS) resolution (QuickBird) and hyperspectral (EO-1 Hyperion) imagery and by employing object-based image analysis. More specifically, the work focused on (1) the separation and mapping of three major post-fire classes (forest regeneration, other vegetation recovery, unburned vegetation) existing within the fire perimeter, and (2) the differentiation and mapping of the two main forest regeneration classes, namely, *Pinus brutia* regeneration, and *Pinus nigra* regeneration. The data used in this study consisted of satellite images and field observations of homogeneous regenerated and revegetated areas. The methodology followed two main steps: a three-level image segmentation, and, a classification of the segmented images. The process resulted in the separation of classes related to the aforementioned objectives. The overall accuracy assessment revealed very promising results (approximately 83.7% overall accuracy, with a Kappa Index of Agreement of 0.79). The achieved accuracy was 8% higher when compared to the results reported in a previous work in which only the EO-1 Hyperion image was employed in order to map the same classes. Some classification confusions involving the classes of *P. brutia* regeneration and *P. nigra* regeneration were observed. This could be attributed to the absence of large and dense homogeneous areas of regenerated pine trees in the study area.

1. Introduction

Vegetation cover plays a key role in soil erosion and land degradation processes (Shakesby et al., 1993; DeBano, 2000; De Luis et al., 2001). The complete or partial destruction of vegetation cover generally leads to many undesirable results in the ecosystem, including an intensification of runoff and erosive processes (De Luis et al., 2003; Gouveia et al., 2010). Wildfire represents one of the main disturbances of land cover in the Mediterranean basin (Trabaud, 1987) in which, during the last decades, a significant increase in the number of fires and the extent of the area burned is being observed (Roder et al., 2008). This, according to Pausas and Vallejo (1999), is the result of an increase in fire risk which can be attributed to many factors including the changes in the use of land as well as the changes on the global climate.

Although, post-fire regeneration depends mainly on onsite initial vegetation and environmental factors, as given by climatic and terrain parameters (Pausas and Vallejo, 1999), not all Mediterranean plant species are able to survive after a fire event (Hodgkinson, 1998; Lloret, 1998; Arianoutsou and Ne'eman, 2000; Retana et al., 2002). As a result, detailed and current information concerning the state and success of post-fire forest regeneration and vegetation recovery is important to monitor land use and land cover changes, to assess economic losses and ecological effects, to understand the way different vegetation species respond to fires (Le Houerou, 1987; Naveh, 1991), to monitor biodiversity, and to model atmospheric and climatic impacts of biomass burning (Pereira and Setzer, 1993; Blackburn and Milton, 1995; Mitri and Gitas, 2004; Van Wagtendonk et al., 2004).

Remote sensing imagery is reported to be particularly suitable not only for mapping burned areas and burn severity (Chuvieco and Congalton, 1988; Caetano et al., 1994; White et al., 1996; Rogan and

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Franklin, 2001; Mitri and Gitas, 2004, 2008), but also for monitoring post-fire plant regeneration and ecosystem recovery (Fiorella and Ripple, 1993; Viedma et al., 1997; Kushla and Ripple, 1998; Díaz-Delgado and Pons, 2001; Riano et al., 2002). As a result, during the last two decades a considerable number of post-fire monitoring studies based on remote sensing has been conducted (Jakubauskas et al., 1990; Fiorella and Ripple, 1993; Marchetti et al., 1995; Viedma et al., 1997; Kushla and Ripple, 1998; Pausas et al., 1999; Díaz-Delgado et al., 2003; Roder et al., 2008; Vila and Barbosa, 2009; Mitri and Gitas, 2010).

In these studies a number of image analysis techniques were employed including image classification (Jakubauskas et al., 1990; Hall et al., 1991; Steyaert et al., 1997; Stueve et al., 2009; Mitri and Gitas, 2010), the use of Vegetation Indices (VIs), and the use of Spectral Mixture Analysis (SMA) (Caetano et al., 1994; Elmore et al., 2000). Out of the different techniques employed to assess post-fire recovery, the use of vegetation indices and especially the NDVI shows to be very popular. This seems to be due to the strongly established relationship of the index with above-ground biomass in a wide range of ecosystems (Carlson and Ripley, 1997; Henry and Hope, 1998; Cuevas-Gonzalez et al., 2009). Apart from the NDVI, the Soil Adjusted Vegetation Index (SAVI) (Huete, 1988; Baret and Guyot, 1991; Qi et al., 1994; Henry and Hope, 1998; Drake et al., 1999; Asner and Lobell, 2000; Elmore et al., 2000; Rogan and Franklin, 2001) is reported to be particularly suitable to be employed in environments which consist of a mixture of vegetation and substrate, i.e. the case of a typical post-fire environment in the Mediterranean.

Although satellite remote sensing has shown to be an essential technology for gathering post-fire ecosystem recovery related information, a number of limitations associated to the limited spatial and spectral resolution of older generation sensors such as Landsat and SPOT as well as on traditional image analysis techniques are reported (Steininger, 2000). In order to overcome these limitations there is a need to explore the potential of new generation sensors with higher spatial (e.g. Quickbird and IKONOS) or spectral resolution (e.g. Hyperion) in order to map accurately even small patches of vegetation recovery and in order to discriminate among different vegetation types and species (Green et al., 1998; Shaw et al., 1998; Mumby et al., 1999; Greiwe and Ehlers, 2005).

Indeed, the development of very high spatial (VHS) resolution and hyperspectral sensors on board of satellites has brought new insight into the provision of post-fire related information such as forest regeneration and vegetation recovery (Pouliot et al., 2002; Riano et al., 2002; Van Wagtendonk et al., 2004; Mitri and Gitas, 2010). According to Gross and Scott (1998), hyperspectral resolution sensors facilitate the identification of features, while VHS sensors allow their accurate location.

The combined use of new generation sensors with enhanced spatial and spectral resolution (Pohl and Genderen, 1998; Zhukov et al., 1999) and the employment of advanced image analysis techniques such as object based image analysis (OBIA) could potentially provide accurate post-fire related information. OBIA, a classification method that deals with objects (i.e. groups of pixels that are generated by image segmentation), is able to use both spectral and contextual information (Benz et al., 2004). According to Wicks et al. (2002), object-based classification may result in increased accuracy, a more appropriate and realistic representation of the environment, and a powerful and flexible framework for further data analysis. OBIA has been successfully employed in burned area mapping (Gitas et al., 2004; Mitri and Gitas, 2004), fire type mapping (Mitri and Gitas, 2006), fire severity mapping (Mitri and Gitas, 2008; Gitas et al., 2009) as well as post-fire vegetation recovery mapping and monitoring using very high spatial resolution imagery (Mitri and Gitas, 2010).

The aim of this study was to map post-fire forest regeneration and vegetation recovery on the Mediterranean island of Thasos using a combination of hyperspectral (EO-1 Hyperion) and very high spatial resolution satellite imagery (QuickBird), and by employing object-based image analysis. More specifically, the work focused on: the separation and mapping of three major post-fire classes, namely, 'forest regeneration', 'other vegetation recovery' and 'unburned vegetation within the fire perimeter', and the differentiation and mapping of the two main forest regeneration classes, namely, *Pinus brutia regeneration* and *Pinus nigra regeneration*.

2. Study area and dataset description

The study area is the island of Thasos, Greece's most northerly island, extending from 24°30′ to 24°48′ East and 40°33′ to 40°49′ North (Fig. 1). Forest vegetation such as *P. brutia* and *P. nigra* is the main vegetation type on the island with other vegetation types also being present. The shrub understory of brutia pine forests of Thasos island varies from site to site and in many cases it is floristically rich, comprising various evergreen sclerophylls (maquis) species (e.g. *Quercus coccifera*, *Phillyrea latifolia*, *Pistacia terebinthus*, *Pistacia lentiscus*, *Arbutus unedo*, *Arbutus andrachne*, *Myrtus communis*), as well as phryganic subshrubs (e.g. *Erica arborea*, *Erica manipuliflora*, *Cistus creticus*, *Cistus salviifolius*, *Paliurus spina-christi*, *Calicotome villosa*). The climatic and soil conditions of Thasos are quite favourable to the establishment and growth of *P. brutia stands* (Spanos et al., 2000).

Two large fires, occurring in 1985 and 1989, resulted in the destruction of approximately 214 km^2 (119 km^2 and 95 km^2, respectively) of different vegetation types.

In a previously conducted study, the natural post-fire regeneration of *P. brutia* forests was studied in two 40–60-year-old forests of Thasos that were burned in the summers of 1985 and 1989 (Spanos et al., 2000). Annual height growth showed a linear regression kinetics throughout the 5- (and conceivably 9-) year-long post-fire period of study, with a yearly increment of 17 cm.

Satellite remote sensing data and field data were collected for this study. A Hyperion image (level 1 radiometric product) acquired on the 1st August 2003 and a QuickBird image acquired on October 28th of the same year were obtained for this study. In addition, two Landsat-TM images acquired a few days after the fires of 1985 and 1989 were used to map the extent of the two burned areas.

Finally, field data were collected during two extensive field surveys carried out in the study area in 2003 and in 2004 in order to locate homogeneous areas of forest regeneration and vegetation recovery. Out of the 66 plots (30 m × 30 m) that were surveyed in the field, 62 plots (located within the fire perimeters) were used in this study (Fig. 1). The field surveys focused on visual assessment of the existing vegetation cover, observation of burned and unburned neighbouring plots, the collection of GPS points and documentation of sites by means of field digital photography.

3. Satellite data pre-processing

The Landsat TM images were atmospherically and geometrically corrected. The Spatially-Adaptive Fast Atmospheric Correction Algorithm (ATCOR2) developed by Richter (1990) and compiled using the MODTRAN-2 and the SENSAT-5 codes, was used for correction (Mitri and Gitas, 2004). The Landsat model (ERDAS Imagine, 2001), which allows ortho-rectification of TM data, was used to geometrically correct the two Landsat-TM images of Thasos. A 10-m grid size Digital Terrain Model (DTM) and a 1:50,000 planimetric map were used in the process. The geometric correction proceeded by identifying ground central points (GCPs) in the Landsat-TM images and on the planimetric map. The two images were then