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# Combining different spatio-temporal resolution images to depict landscape dynamics and guide wildlife management

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ABSTRACT

Raptors are emblematic species of high conservation value and significant ecological role. Their conservation is of particular importance and it relies on the conservation of their habitats and the constant monitoring of their dynamics. In the current study we investigate land cover changes over the period 2001–2011, in one of the most important reserves for raptor conservation in Europe, the Dadia-Lefkimi-Soufli Forest National Park. Very high and high spatial resolution satellite data were integrated in a single analysis, in order to exploit the high spatial accuracy of the former and the high temporal and spectral resolution of the latter. The results suggest that the applied method increases the overall accuracy of the mapping product from 73% to 89%, providing a tool to land managers and conservationists to study landscape dynamics and guide wildlife management. The analysis of land use changes revealed that wildfires of high intensity and large extent, constitute a new threat for the ecological integrity of the reserve. If the currently observed trend of wildfire behavior in Greece and southern Europe continues it is likely to affect the core zones of forest reserve, which consist primarily by dense forests with high fuel load, with detrimental effects for wildlife. The most important land cover change observed is the significant reduction of open areas, which form the main hunting areas for raptors. Open areas appear to be encroached by forest, leading to loss of heterogeneity which has been reported to be associated with high biodiversity. The results reveal the need for more active management measures that would decrease the risk of large stand replacing fires and would ensure a suitable landscape structure for raptors.

## 1. Introduction

Forests are extremely valuable ecosystems, associated with a number of ecosystem services of significant importance for human well-being. Although biodiversity conservation stands on the top of the list of desired ecosystem services, carbon storage, water regulation and supply, wood and non-wood products, recreation, soil protection and nutrient cycling are also important and often associated with high biodiversity (Mori et al., 2017). For biodiversity conservation in particular, the importance of forests is reflected to the high percentage, almost 50%, with which they participate in the Natura 2000 network (European Commission, 2015).

For centuries and millennia, European forests have been shaped by diverse human land uses, and particularly agriculture and pastoral activities, and natural disturbances, including wildfires, windstorms and insect outbreaks (Bebi et al., 2017; Kulakowski et al., 2017; Thorn et al., 2017). In Mediterranean region the combined action of land clearance, cultivation, pastoral grazing in the uplands and drainage of wetlands (Naveh and Dan, 1973; Pons and Quezel, 1985), had detrimental effects on the landscape with the most important being the extinction or many large mammals, soil erosion, changes in hydrology and the restriction of forests by 85% (Blondel, 2006). Although forest land conversion to agriculture remains an important environmental issue, especially in the tropics (Abram et al., 2014), in Europe and generally in more wealthy regions of the world an opposite trend is observed since the mid of the 20th century. A major shift in traditional land uses associated with socioeconomic changes and urbanisation has led to the abandonment of agricultural activities in marginal environments, significant reduction of pastoral activities and subsequently to a gradual increase of forest cover in Europe and elsewhere (San Roman Sanz et al., 2013; Loran et al., 2016; Conedera et al., 2017; Vacchiano et al., 2017). Findings on the consequences of this trend on biodiversity and nature conservation are far from reaching a convergence.

Several studies indicate a negative response of biodiversity to land

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abandonment as a result of habitat loss and landscape homogenisation (e.g. Farina, 1997; Preiss et al., 1997; Labaune and Magnin, 2002; Kiss et al., 2004; Otero et al., 2015; Queiroz et al., 2014), recommending the adoption of management practices and policy initiatives to halt further land abandonment and reverse the negative impacts (MacDonald et al., 2000). In Greece and the Balkans, in particular, Zakkak et al. (2015) identified that land abandonment leads to significant decrease of overall bird species richness, along with a significant decline of farmland birds and of birds with high conservation importance for Europe. However, Navarro and Pereira (2012) make a strong case in favor of rewilding the abandoned areas of Europe, demonstrating the positive consequences in biodiversity and other ecosystem services, (see also Preiss et al., 1997; Queiroz et al., 2014). A significant contribution of land abandonment in carbon sequestration and increased carbon stock in terrestrial ecosystems is also pointed out in the literature, demonstrating its positive impact on mitigating climate change (Silver et al., 2000; Grau et al., 2004).

Another important trend, related to land abandonment and forest expansion in the Mediterranean region, is the biomass increase, which in turn increases the severity of burning (Pausas, 2004; Moreira et al., 2010; Koutsias et al., 2012). Given the strong association between fire behavior and weather patterns (Koutsias et al., 2013), and the projected climatic changes in the Mediterranean Europe, the fire potential is likely to increase by the end of the century, as a result of warmer and dryer conditions (Liu et al., 2010). This trend will increase the frequency of large catastrophic fires with possibly detrimental effects on biodiversity and long term ecosystem sustainability (Mouillot et al., 2005).

Monitoring land use changes is essential in meeting the Europe's conservation objective to halt the loss of biological diversity by 2020 and for the implementation of the Streamlining European Biodiversity Indicators 2020 (SEBI 2020; European Environment Agency, 2012). Recent advances in remote sensing data availability and quality (Drusch et al., 2012; Roy et al., 2014), offer a great tool to ecologists and land managers to achieve high quality, spatially explicit data for monitoring trends in extent, condition and vulnerability of ecosystems (SEBI 04), in a cost efficient manner. Mapping dynamic and diverse landscapes, however, can be quite challenging and the use of time series satellite data is indispensable (Lucas et al., 2007). While the use of Very High Spatial Resolution (VHR) data can ensure spatial and thematic accuracy, especially at fine scales, obtaining a time series dataset of VHR images has a relatively high cost which management bodies are often unable to afford. On the other hand High Resolution (HR) data, such as Landsat TM, ETM +, 8 and Sentinel 2 are offered free of charge, with high spectral resolutions, offering opportunities for the classification of entities that cannot be separated using the visual and near Infrared spectral wavelengths alone (Zhang et al., 2017).

In the current study data from different sensors and different spatial and temporal resolution were employed to study landscape dynamics over the period 2001–2011 in the protected area of Dadia-Lefkimi-Soufli Forest National Park by integrating, in order to guide future wildlife management. The aims of the current study are a) to assess the efficiency of integrating high and very high resolution satellite images in improving the accuracy of the mapping process, b) to investigate the land use changes that have occurred in the area over the decade 2001–2011 and c) to evaluate the observed landscape dynamics on wildlife habitats based to an existing animal habitat suitability analysis and the conservation objectives of the area.

## 2. Materials and methods

### 2.1. Study area

The study area is the Dadia-Lefkimi-Soufli Forest National Park (henceforth Dadia NP) in north-eastern Greece. It is a designated protected area since 1980 for its high ornithological importance and it is also a Natura 2000 site (GR1110002 and GR1110005). It constitutes one of the most important conservation sites in Europe, hosting 36 out of the 38 raptor species of Europe, including cinereous vulture (*Aegypius monachus*), griffon vulture (*Gyps fulvus*), golden eagle (*Aquila chrysaetos*) and other (Poirazidis et al., 2004; Poirazidis et al., 2011). The main land cover types are coniferous stands of Corsican pine (*Pinus nigra*) and Calabrian pine (*P. brutia*), pure oaks (*Quercus sp.*) stands, mixed stands of pines and oaks, evergreen broadleaves, open areas used for grazing as well as agricultural areas and settlements.

It is a complex landscape with an altitudinal range between 20 and 640 m with varying slopes and aspects. The climate is sub-Mediterranean with hot and dry summers while in higher altitudes it approximates the continental climatic type with relatively cold winters and observed temperatures between − 19 and 40 °C. The average annual precipitation is 732 mm and the average annual temperature ranges between 13.7 and 15 °C, while the complex relief offers a range of microhabitats suitable for different vegetation types (Catsadorakis and Källander, 2010).

The total size of the area is approximately 43,000 ha and it consists of two core areas, of approximately 7250 ha and a buffer zone. The two core areas are strictly protected where only specific human activities (like nomadic grazing, traditional agriculture, and ecotourism) are allowed. In the buffer zone on the other hand only controlled human activities are allowed, including forestry, agricultural and pastoral activities. Both zones are of conservation importance since the buffer zone hosts the main colonies of cinereous vulture and many of the breeding raptors territories in the Park (Poirazidis et al., 2011). It is a dynamic landscape with significant changes in land cover having occurred over the second half of the 20th century, primarily as a result of land abandonment and reduction of livestock, resulting in pines encroaching over traditional grazing areas (Triantakonstantis et al., 2006). Furthermore, a large wildfire occurred in the area in August 2011 affecting a large part in the southwest of the reserve.

### 2.2. Integrating data of different spatial and temporal resolution

The idea of integrating satellite data from different sources has been successfully employed for vegetation and carbon mapping in the tropics (Abram et al., 2014; Abram et al., 2016) and for vegetation and fuel mapping in Mediterranean (Mallinis et al., 2016). However, the current study is the first which integrates VHR data (0.5 m) with HR data (30 m). In order to assess the efficiency of integrating data with great differences in spatial and spectral resolutions, preliminary mapping was performed in two stages, in a subset of the study site covering an area of 23,500 ha. In the first stage only the VHR data were employed while in the second the VHR data were integrated with a year round set of HR images and the assessment was based on the accuracies achieved.

Two mosaicked Geoeye 1 pan-sharpened images at a spatial resolution of 0.5 m, acquired in October 2011, were the only ones used in the first stage. Geoeye 1 delivers panchromatic and multispectral data at spatial resolutions of 0.46 m and 1.84 m respectively (nominal at Nadir). The panchromatic image covers the part of the wavelength from 450 to 800 nm, while the multispectral bands cover the 450–510 nm, 510–580 nm, 655–690 and 780–920 parts of the electromagnetic spectrum in four bands. The images were orthorectified, and principal and inverse components transformations were applied, obtaining two and four additional layers of information respectively. Normalized Difference Vegetation Index (NDVI) was also calculated and used in the analysis. A step-wise Object-Based Image Analysis (OBIA) in eCognition Developer v.9 was employed for the classification, which generates and classifies 'objects' by segmenting images into groups of spectrally similar pixels and spatial characteristics (Benz et al., 2004; Bock et al., 2005). OBIA has several advantages compared to traditional pixel based methods when applied on VHR data, since they deal efficiently with high, within class, variability while at the same time they can employ various shape, texture and context characteristics in the classification