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An innovative environmental risk assessment approach to a Mediterranean coastal forest: the Presidential Estate of Castelporziano (Rome) case study

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Abstract - Thanks to their ability to generate ecosystem services, forest ecosystems have a significant social, economic and environmental impact on the development of many regions in the world, especially those located in urban and peri-urban areas.Today, increased forest vulnerability is reflected in an increased number of episodes of severe decline associated mainly with drought. In this context, the Mediterranean area shows high forest vulnerability and a subsequent decline in its natural renewal rate. In this scenario, the aim of this research is to assess the sustainability of a protected pristine deciduous oak forest near Rome via the development of a forest health condition monitoring tool based on the application of multispectral satellite data and the identification of silvicultural models suitable to promoting natural forest renewal. Data and results from research in the case study area, the Natural State Reserve of Castelporziano (Rome), have potential as an important decision making tool in sustainable forest management.

Keywords - risk assessment, oak decline, remote sensing, NDVI, urban forest.

Introduction

Mediterranean forests are one of the world's biodiversity hotspots. In recent centuries, mainly as a result of human activities, approximately 70% of the original Mediterranean forests and shrub lands have been destroyed and, since 1990, what remains has been listed as critical or endangered (Millennium Ecosystem Assessment 2005). For these reasons, the Mediterranean basin has been identified as a key high vulnerability area, especially susceptible to forecast climate changes, with greater increases in temperature and aridity due to its geographical position between the arid subtropical climates of North Africa and the climates of Central Europe (Acacio et al. 2009, Di Filippo et al. 2010, Gentilesca et al. 2014, Colangelo et al. 2017).

In this scenario, deciduous oak forest is one of the most vulnerable Mediterranean landscapes, especially along the coast. Deciduous oak decline has been defined as a condition characterized by episodes of premature, progressive tree or stand vigour loss without obvious evidence of physical injury or attack by a primary disease or pest and in which several damaging agents interact and bring about a serious decline in tree health (FAO 1994). In this context, there are many factors driving tree decline, some of which are abiotic, biotic and anthropogenic. Climatic anomalies, namely increasing temperatures and repeated and prolonged periods of drought, as well as recurring wildfires, are among the most important factors causing this phenomenon. With regards to drought-induced oak dieback, two non-mutually exclusive mechanisms are involved: *(i)* hydraulic failure due to a drastic loss of xylem conductivity and *(ii)* carbon starvation when carbon demands are not met (Costa et al. 2010, Manes et al. 2010). As with other Mediterranean forests, deciduous oak forest growth is favoured by precipitation from autumn of the year prior to ring formation to spring of the year of ring formation, whereas high temperatures during spring limit growth (Romagnoli et al. 2018).

In Italy, isolated oak decline cases have been observed since the end of the last century. First identified in north-eastern Italian forests, where *Quercus robur* L. was the species most affected, this decline spread subsequently to central and southern Italy, mainly to *Quercus cerris* L., *Quercus frainetto* Ten. and *Quercus pubescens* Willd., in both pure

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and mixed forests. The phenomenon affected most coastal Mediterranean ecosystems, for which summer water availability is usually the major limiting factor (Maselli 2004).

Today, common survey tools used in the field of Geographic Information Systems show limitations as regards detecting the different phases of tree decline. Oak mortality and severe decline can be easily observed through the visual interpretation of aerial photos. Nonetheless, trees at an early stage of decline, i.e. trees that are still green but are beginning to defoliate (Modica et al. 2016) are difficult to identify. Such trees may die back in subsequent years or become more vulnerable when stress next occurs and, for this reason, affected areas need to be detected and treated to prevent huge ecological and economic losses.

Therefore, an efficient environmental risk assessment monitoring tool is needed if effective strategies to support sustainable forest management are to be planned, especially in protected areas.

With this in mind, this research developed an innovative tool for environmental risk management to identify the silvicultural treatments best suited to clearing the way for natural forest renewal processes. Moreover, to promote sustainable preservation of these natural environments in the future, a high frequency remote sensing monitoring system was developed in 2015 based on Sentinel-2 and LANDSAT multispectral images and the NDVI index (Bannari et al. 1995, Ogaya et al. 2015, Korhonen et al. 2017).

Materials and methods

Study area

The study area (E 41° 440' 40.4000"; N 12° 230' 59.4900", datum WGS84) is an incredibly rich natural environment with a varied cultural heritage. From the fifth century onwards, it remained part of the Papal States until the nineteenth century, when it became an Italian Royal family hunting reserve. Finally, at the end of World War II, Castelporziano was chosen as the Italian republic's Presidential estate on the basis of its notable environmental and cultural value.

The Castelporziano Presidential estate obtained State Nature Reserve status in 1999. It covers over 6,000 ha, extending south–southwest of Rome towards the Tyrrhenian Sea (Fig. 1). The nature reserve comprises two sites of community importance (SCIs): a coastal area (IT6030027) and a lowland oak woodland area (IT6030028). This area, including neighbouring Castelfusano, represents what remains of the forest system which once charcterized the Tiber River delta and its neighbouring zones. The area is mostly flat, except for some gentle gradients to the north which rise to heights of no more than 80 m a.s.l. The coastline features a sand dune system comprising ancient red sands and more recent grey sands, and several temporary bodies of water, due to seasonal rain and a subsequent aquifer level rise. The presence of characteristic hydrosoils means that this physical conformation has an important environmental role to play. Its vegetation type was once very common, but has almost entirely disappeared now not only in the territory of Rome, but also in many Tyrrhenian coastal areas.

The area has remained substantially unchanged over recent decades, allowing vegetation to grow undisturbed and thus develop and mature considerably. For these reasons, but also due to its concentration of extremely ancient plants (e.g., *Quercus cerris* L., *Quercus pubescens* Willd., *Quercus robur* L.) classified as "monumental trees" (Recanatesi et al. 2013, Recanatesi 2015) on the basis of age and size criteria (many are more than 400 years old), Castelporziano stands out in the Mediterranean area for its unique environment.

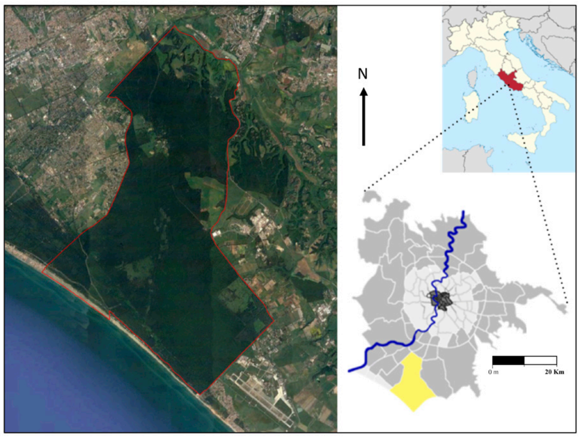

Figure 1 - Study area of Castelporziano (E 41° 440' 40.4000''; N 12° 230' 59.4900'', datum WGS84): on the left, aerial photo and borders (red line); on the right, a territorial description of the study area (yellow), Tiber river (blue), Municipality of Rome (dark gray), and city of Rome (light gray and black).

Throughout the last three decades, this unique environment has shown significant diffuse decline in forest health conditions and natural renewal capacity and Figure 2 shows several examples of the dieback detected in Castelporziano. In this regard, the current Forest Management Plan – (FPM) (Giordano et al. 2006, Scrinzi et al. 2016) has identified the following factors limiting survival and growth of deciduous oakwoods: *(i)* forest senescence; *(ii)* high wildlife pressure; *(iii)* lack of natural forest renewal.

To deal with these limiting factors, a range of action has been taken to acquire remote sensing and field data enabling the ongoing process of oak-forest dieback to be better understood and useful advice in the management of the protected area given.

Silvicultural treatments

As regards analysing the low natural renewal rate of natural deciduous oak forest due to wildlife activity, the following action was undertaken: *(i)* in 2012, an experimental area, Campo di Rota (12 ha), was enclosed to exclude it from wildlife pressure; *(ii)* in 2013 this area was subjected to two different levels of silvicultural thinning to promote natural forest renewal; *(iii)* from 2013 to the present, three plots (25 m^2) have been monitored to quantify the degree to which natural renewal has taken place; *(iv)* in 2015 a remote sensing-assisted risk rating tool was adopted to assess oak canopy cover health status.

Figure 2 - Castelporziano deciduous oak forest: different rates of health decline.

Field data

The effects on natural renewable capability deriving from the various silvicultural models used in the fenced off area in 2013 differ in their harvested intensity. In Campo di Rota, as shown in Figure 3, the fenced off area was divided into three plots, each of which was subjected to different levels of silvicultural thinning. In Surfaces A (6 ha), B (4 ha) and C (2 ha), 70%, 90% and 0% (witness area) thinning respectively of the dominant forest layer - mainly Mediterranean scrub with an average volume of 350 m^3 ha^{-1} - was enacted. To quantify the effects of different silvicultural treatments on natural deciduous oak forest renewal, three plots (25 m^2) were set up in each treated area. Starting from 2013, naturally regenerated oak seedlings were surveyed every year in August. Figure 3 shows the three plot areas and the Campo di Rota fenced off area.

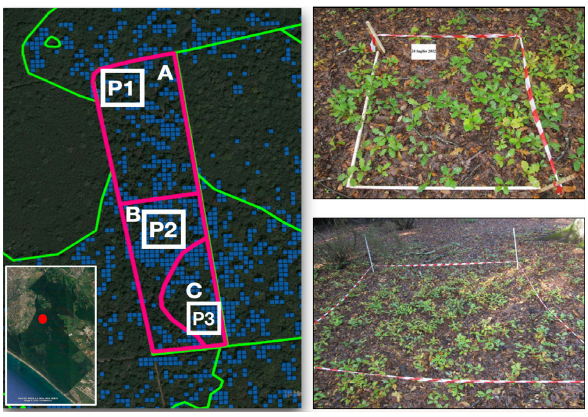

Figure 3 - On left, Campo di Rota experimental area (red line) with the sub-areas A, B and C and the plot areas for the census of the natural renewal of the oak forest, on the right, P1, P2 and P3.

Satellite data

Specifically, for a better understanding of ongoing crown dieback, a georeferenced database for the deciduous oak forest was developed at Sentinel-2 grid scale (100 m^2) using GIS software program Qgis 2.4.0 Chugiak, with the goal of detecting the presence or absence of deciduous oak (Recanatesi et al. 2018a, Recanatesi et al. 2018b). The creation of this georeferenced database was made necessary by the high spatial heterogeneity in terms of density of deciduous oaks at the forest unit management scale (FUM), Figure 4.

Figure 4 - Castelporziano deciduous oak forest: examples of heterogeneous distribution of oak canopy cover detected at the forest unit management scale (white line). The green dots represent cells of the Sentinel-2 grid with presence of deciduous oak's canopy.

For the purposes of risk assessment monitoring related to ongoing crown decline in Castelporziano, forest health status was examined by applying the NDVI index in a diachronic way from 2015 to the present (Chiesi et al. 2011). For this purpose, a georeferenced dataset of multispectral images was acquired using Sentinel-2 from 2015 to the present and historical trends concerning the NDVI index were examined via a series of Landsat-5 historical data for 1989, 1990, 2000 and 2009 (Bannari et al. 1995). All the multispectral data, Sentinel-2 and Landsat-5, were applied to grid cells in which the presence of oak canopy had been previously detected only.

Figure 5 shows the method used to determine the vegetative health of the deciduous oak forest using the NDVI index with Sentinel-2 images. Obviously, using the deciduous oak canopy 'mask' at the Sentinel grid scale (100 m^2) means that the surface investigated with Landsat data (900 m^2 resolution) is lower.

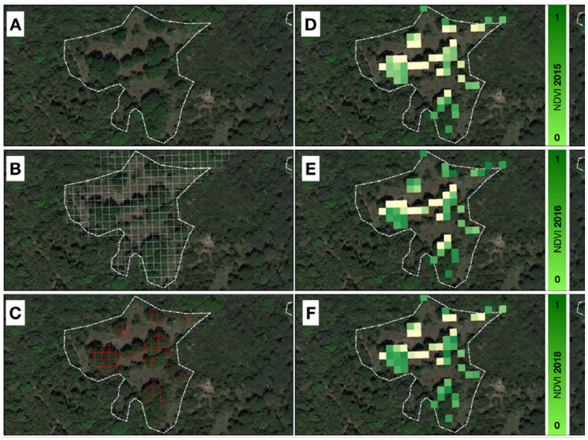

Figure 5 - (A) Forest Unit Management (white line); (B) Sentinel-2 grid "mask"; (C) presence of oak deciduous canopy (red squares); (D, E and F) NDVI values detected for deciduous oak canopy for years: 2015, 2016 and 2017.

Results

With reference to the preliminary results regarding the effects of various silvicultural treatments on natural renewal capability, seedling numbers in the three observed plot areas show different trends. In Plot Areas 1 and 2 silvicultural treatments appear to be useful in favouring the natural renewal process, as shown in Figure 6. Good acorn seeding and germination ability was observed in the first spring after the fence was put up (2013), with 95 and 112 seedlings respectively. In 2015 a significant reduction (-20.5%) in seedling numbers was observed in Plot Area 2, while in Plot Area 1 a 16.5% decrease was observed as compared with 2014. Another noticeable difference between the above mentioned Plot Areas was trends over the last two years of the observation period: 2017 and 2018. In these two years, a remarkable difference in trends emerged with seedling numbers remaining constant (37 seedlings) in Plot Area 1 and negative trends in Plot Area 2 which will lead to the death of all the seedlings over the next two years if it continues at this rate.

Lastly, no deciduous oak seedlings were detected throughout the entire observation period in Plot Area 3, a witness area not subjected to silvicultural treatment.

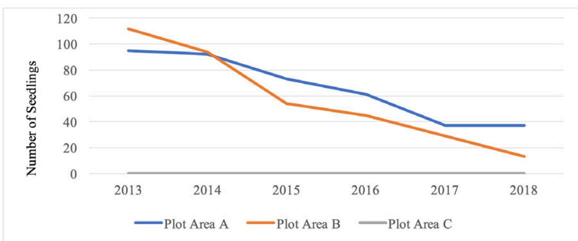

Figure 6 - Number of seedlings in the plots considered for the period 2013-2018.

Regarding the monitoring system carried out with Sentinel-2 images and based on the application of the NDVI index to the deciduous oak canopy, widespread decline was detected from 2015 to 2018, as Figure 7 shows. Given the short time frame available when using Sentinel-2, further analysis was carried out using LANDSAT-5 images. Here, the availability of acquired data began in the early 1980s allowing for more in-depth vigour status trend analysis over time, as shown in Figure 8.

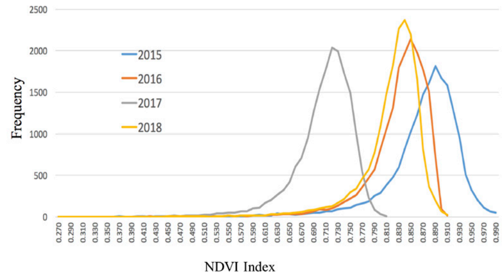

Figure 7- NDVI index detected by Sentinel-2 satellite images.

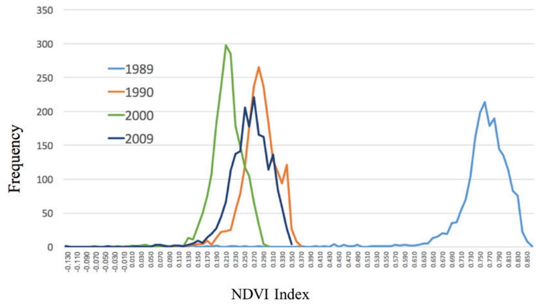

Figure 8- NDVI index detected by Landsat-5 satellite images. Data refers to the 37% of the "mask" surface.

Conclusions and Discussion

Today Mediterranean oak forest stand dieback is an extremely important topic within the scientific community, especially as regards protected areas located in urban and peri-urban areas, environments requiring preservation via versatile and efficient analysis tools for the implementation of forest management operations.

This research paper reports the preliminary results from the application of various silvicultural criteria to facilitate the renewal of a protected forest. To monitor vegetation decline, a multispectral image dataset was created using Sentinel-2 and Landsat-5 satellites.

Surveys of seedlings in the three plot areas showed that competition for light is a limiting factor in natural renewal. Where forest thinning (Area Plot

3) was not done, dominant forest stand species do not allow light to reach the ground, thus preventing seedlings from surviving. In contrast, in the areas subjected to silvicultural intervention involving thinning dominant plants, natural seedling generation was favoured. In particular, Plot Area 1 was found to be the most efficient and this probably depends on better plant density as compared to Plot Area 2 where the removal of 90% of the dominant floor has favoured the dissemination of Mediterranean scrub, limiting the development of oak seedlings over time.

Undoubtedly, the data acquired must be long term if it is to shed light on this ongoing process. Overall, data acquisition is intended to provide helpful specific guidelines for forest planning strategies in protected areas. Monitoring ongoing decline via remote sensing of multispectral images according to the NDVI index is an effective tool that allows vegetative conditions of concern to be monitored, thanks to Sentinel-2's high acquisition frequency.

In addition, a presence/absence of oak canopy 'mask' generates an accurate analysis which, given the spatial heterogeneity of the plants in the Mediterranean environment, is the only way in which accurate and effective information at a forest particle scale can be built up.

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