

The Contribution of Remote Sensing and Silvicultural Treatments to the Assessment of Decline in an Oak Deciduous Forest: The Study Case of a Protected Area in Mediterranean Environment

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Abstract. Thanks to their ability to produce ecosystem services, forest ecosystems have a significant social, economic and environmental impact on the development of many regions in the world, especially when located in urban and peri-urban areas.

Today, increased forest vulnerability is being reflected in a larger number of severe decline episodes 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 the present research is to assess sustainability of a protected pristine deciduous oak forest near Rome, developing a forest health condition monitoring tool based on the application of multispectral satellite data, and through the identification of silvicultural models appropriate for promoting natural forest renewal.

The preliminary results of this research indicate how the exclusion of wildlife through fenced areas significantly favors the natural renewal of the forest, especially when silvicultural actions such as thinning are carried out. It has also been ascertained through the use of multispectral satellite data that there is a widespread decline in the health vegetative state of the deciduous oak surfaces, due to a widespread senescence of the forest. In the addressed study area, the Natural State Reserve of Castelporziano (Rome), data and results from this research can work as an important decision tool for sustainable forest management.

Keywords: Protected area · Risk assessment · Oak decline · Remote sensing · NDVI · GIS · Sentinel-2 · Landsat 5

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1 Introduction

The Mediterranean forest area is one of the world's biodiversity hotspots. In the last centuries, mainly due to human activities, approximately 70% of the original Mediterranean forests and shrub-lands were destroyed and, since 1990, the remaining cover has been listed in critical or endangered conditions [1, 2]. For these reasons, the Mediterranean basin has been identified as a key area for its high vulnerability as an area especially vulnerable to these predicted 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 [3–6].

In this scenario, deciduous oak forest is one of the most vulnerable Mediterranean landscape, especially along the coastal area. Deciduous oak decline is defined as a condition characterized by episodes of premature, progressive loss of tree or stand vigor 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 conditions [7–10]. In this context, driving factors of tree decline are numerous, including abiotic, biotic and anthropogenic ones. Climatic anomalies, namely increasing temperatures, repeated and prolonged periods of drought, as well as recurring wildfires are among the most important factors involved in 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 [11, 12]. As with other Mediterranean forests, oak deciduous forest growth was favored by precipitation from autumn of the year prior to ring formation to spring of the year of ring formation, whereas high temperatures during spring limited growth [13].

In Italy, isolated oak decline cases have been observed since the end of the last century. First identified in northeastern Italian forests, where Quercus robur L. was the most affected species, such decline spread thereafter in central and southern Italy, mainly on Quercus cerris L., Quercus frainetto Ten. and Quercus pubescens Willd., in both pure and mixed forests. The phenomenon affected most coastal Mediterranean ecosystems, for which summer water availability is usually the major limiting factor [14].

Today, common survey tools used in the field of Geographic Information Systems (GIS) show limitations for detecting the different phases of tree decline. Oak mortality and severe decline can be easily observed through the visual interpretation of aerial photos. Nonetheless, it is difficult to identify trees that are in early stage of decline, i.e. the trees that are still green but are beginning to defoliate [15]. These trees may die back in the next few years or become more vulnerable when next stress occurs and, for this reason, the affected areas need to be detected and treated to prevent huge ecological and economical losses.

Therefore, an efficient monitoring tool for environmental risk assessment is needed for planning effective strategies to support sustainable forest management, especially in protected areas.

With this aim, in the present research, an innovative tool for environmental risk management was developed to identify the most suitable silvicultural treatments for clearing the way to natural renewal processes of the forest. Moreover, to promote a sustainable preservation of these natural environments in the future, from 2015 a high

frequency remote sensing monitoring system was arranged based on Sentinel-2 and Landsat-5 multispectral images and NDVI index [16–18].

At this purpose, satellite imagery provides an efficient means to retrieve information on the status and extent of forest resources and changes thereof. The large area coverage and high spatial resolution of newly launched optical and radar satellite systems offer new opportunities to remotely estimate and access land cover information on a wall-to-wall basis. At the same time, the high temporal resolution and capacity to acquire data on a weekly basis improves the capability to detect most recent land cover changes such as health status. The utilization of dense time series of multi-temporal and multi sensorial satellite imagery, which the European Space Agency (ESA) Sentinel-2 missions data is well suited for, can address challenges caused by phenological changes of forest canopies between the seasons and data availability restrictions due to clouds [19].

2 Materials and Methods

2.1 Study Area

The study area of Castelporziano (E 41°440 40.4000; N 12°230 59.4900, datum WGS84) is characterized by an incredibly rich natural environment and the presence of several cultural heritages. From the fifth century onwards, it was under the control of the Vatican State, until the nineteenth century, when it became a hunting estate of the Italian Royal family. Finally, at the end of World War II, Castelporziano was chosen as the presidential estate of the Italian Republic, thanks to its notable environmental and cultural value.

The presidential estate of Castelporziano obtained the status of Nature State Reserve in 1999. It covers over 6,000 ha, extending south–southwest of Rome towards the Tyrrhenian Sea (Fig. 1). There are two sites of community importance (SCIs) within the nature reserve: the coastal area (IT6030027) and the lowland oak woodland (IT6030028). This area, including the neighboring territory of Castelfusano, represents what remains of the forest system which once characterized the delta of the River Tiber and its neighboring zones. The area is mostly flat, except for some smooth slopes toward North which rise to a height of no more than 80 m a.s.l.. The coastline is characterized by a dune system, comprising ancient red sands and more recent grey sands. Within the dune system, several temporary water bodies are present, due to seasonal rain and the subsequent rising of the aquifer. Thanks to the presence of typical hydrosoils, this physical conformation has an important ecological role. Its vegetation type was once very common, but has now almost disappeared not only in the territory of Rome, but also along many Tyrrhenian coastal areas.

The territory has remained substantially unchanged over the last few centuries, allowing an undisturbed growth of the vegetation, which was able to develop and mature considerably. For these reasons, but also due to its concentration of very ancient plants (e.g., Quercus cerris L., Quercus pubescens Willd., Quercus robur L.) classified as "monumental trees" [20, 21] according to age and size criteria (many of them are more than 400 years old), Castelporziano stand out in the Mediterranean area for its unique environment.

From a climatic point of view, the site is classified as Mediterranean, referring to the climatic data of Rome—Collegio Romano (N 41°53'55" – E 12°28'50"), with a hot and

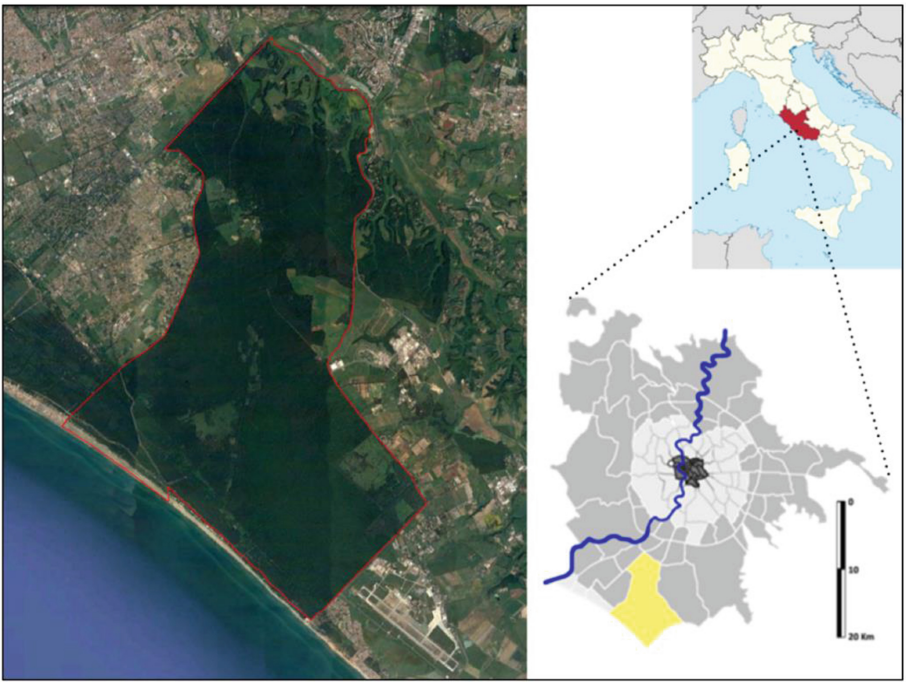


Fig. 1. Study area of castelporziano (E 41°440 40.4000; N 12°230 59.4900, datum WGS84): On the left, aerial photo and borders (red line); on the right, a territorial description of the study area (yellow), tiber river (blue), municipality of rome (dark gray), and city of rome (light gray and black). (Colour figure online)

dry period between May and September. The mean annual total precipitation in Rome (1862–2013) is 711 mm, while the mean annual temperature is 16.1 °C [22].

Throughout the last three decades, this unique environment showed a significant diffuse decline in forest health conditions and in its natural renewal capacity, Fig. 2 shows several examples of the dieback detected in Castelporziano. In this regard, the current Forest Plan Management – (FPM) [23, 24] has identified the following limiting factors to the sustainability and growth of deciduous oak woods: (i) senescence of the forest; (ii) high pressure of wildlife; (iii) lack of forest natural renewal.

Themes (ii) and (iii) are closely related, in fact, the protected area of Castelporziano is strongly affected by wild mammals impact [25]. Mainly the boars (Sus scrofa majori) caused the lacking of plant species recruitment in the deciduous oak forests [26] and a change in the structure of the humus systems. The populations of the ungulates have in general high density and are regulated by density-independent (oak seed productivity) and density-dependent factors. Their increase in the last times are due to lacking of predators, both man and animals.

To deal with these limiting factors, several actions were conducted for the acquisition of field data and remote sensing. This allowed to better understand the ongoing process of



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

oak-forest dieback in order to provide useful advice in the management of the protected area.

2.2 Silvicultural Treatments

For the analysis of the low natural renewal rate of deciduous oak forest due to wildlife activity, the following actions were undertaken: (i) in 2012, a forest parcel (FP) located inside the study area, named "Campo di Rota" (12 ha surface), was fenced to exclude it from wildlife pressure; (ii) in 2013 this FP was divided in three test parcels (TP) named: A, B and C, two of them (TP-A and TP-B) were subjected to different rate of silvicultural thinning to promote the natural renewal of the forest and one of them (TP-C) treated as witness area; (iii) from 2013 to 2018, three square sample areas (SA), each one with a surface of 25 m2 and located under a mature oak canopy, have been monitored to quantify the natural renewal degree by annual seedlings counting.

2.3 Field Data

The effects on natural renewable capability derived by the different silvicultural models applied in the fenced area in 2013 differ according to their harvested intensity. In TP-A (6 ha), TP-B (4 ha) and TP-C (2 ha), a 70%, 90% and 0% (witness area) thinning of the dominated layer of the forest mainly characterized by Mediterranean scrub and with an average volume of 350 m3 ha-1 [24] was performed respectively. To quantify the effects of different silvicultural treatments on the natural renewal of the deciduous oak forest, three SAs have been positioned in each TP. Starting from 2013, the naturally regenerated oak seedlings were counted every year in August.

The census of natural renewal was carried out by analyzing the variation in the number of plants year by year throughout the observation period. To achieve this goal, tags were placed to distinguish the plants according to their year of birth.

In Fig. 3 the fenced area of Campo di Rota is show with the three TP (A, B and C) and their relative SAs (1, 2 and 3).

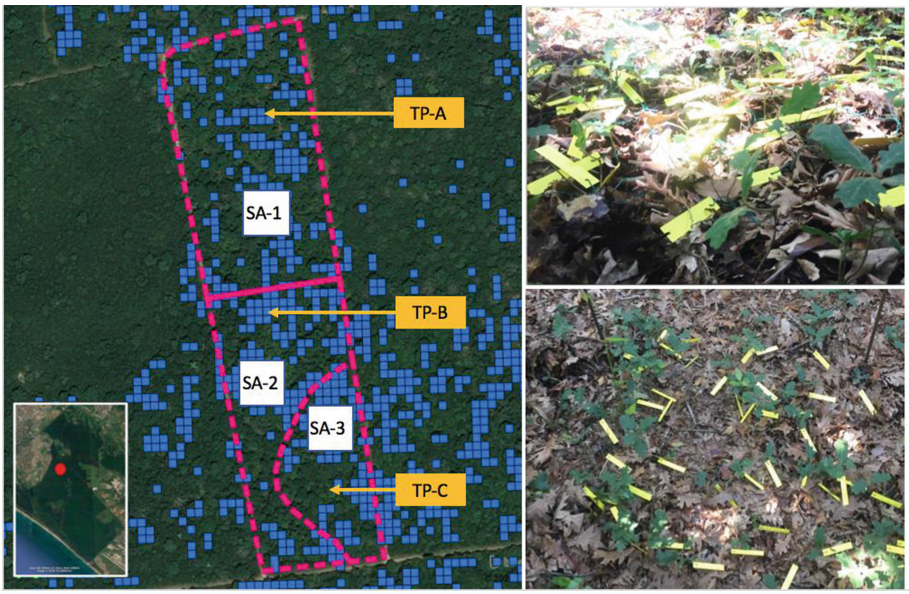


Fig. 3. On left, Campo di Rota experimental fenced forest parcel (FP) (red dotted line) with the three test parcels (TP): A, B and C and the sample areas (SAs) (not in scale) for the census of the natural renewal of the oak forest: SA-1, SA-2 and SA-3. The blue dots indicate the presence of oak's canopy at Sentinel-2 grid scale. On the right, examples of oak natural renewal referred to 2013 detected in: SA-1 and SA-2. (Colour figure online)

2.4 Satellite Data

Starting by 2015, a remote sensing-assisted risk rating tool was adopted to assess the health status of the deciduous oak's canopy for the whole study area (about 4.000 ha).

Specifically, to better understand the ongoing crown dieback, a georeferenced database for the deciduous oak forest was developed at Sentinel-2 grid scale (100 m2) using the GIS software program Qgis2.4.0 Chugiak, with the goal of detecting presence or absence of deciduous oak crown [27].

In fact, due to the high heterogeneity in terms of spatial distribution and silvicultural structures in Castelporziano oak forest, a preliminary analysis was carried out on the forest canopy cover, on a grid scale (100 m2), to specifically identify the cover of the deciduous oak canopy.

To achieve this, we used a Sentinel-2 derived grid with a spatial resolution of 100 m2. This allowed us to apply the NDVI specifically to detect the health condition of only the deciduous oak canopy.

To reach this goal, a georeferenced database was set up using: (i) information provided by the Castelporziano forest management plan (FMP) concerning the different heights referred to the dominant and dominated layers of the forest; (ii) CHM LiDAR data to separate dominant and dominated stand forest; and (iii) a diachronic set of multispectral Sentinel-2 and Landsat-5 images.

The analysis of the dominant and dominated layers of the forest was carried out by consulting the FMP of Castelporziano at the FP scale, in terms of height referred to dominant forest (oak) and dominated forest layers (Mediterranean scrub and/or bare soil).

Table 1. Main silvicultural characteristics of the FPs analyzed

Castelporziano deciduous oak forest structures	ID code	Surface (ha)	Mean Oak canopy cover (%)	Average height (m)		Forest canopy composition	
				Dominant layer of the forest	Dominated layer of the forest	Deciduous Oaks	Non-Deciduous Oaks
Transitional forests of deciduous oaks and Ostrya carpinifolia	21	156	73	9	7, 5	Qc; Qc; Qr; Qp	Pl; Qi; Ac; Fo; Cr; Pp
Transitional forests of deciduous oaks and Mediterranea scrub	22	181	62	8, 5	6, 5	Qc; Qf; Qr; Qp	E; Pl; Cr; Co
Transitional forests with prevalence of deciduous and mixed oaks	24	294	69	8, 5	7	Qr; Qf; Qc; Qp	Pp; Pl; Co; Qs; Qi; Qpt; Um
Coppice of deciduous oaks with Ostrya carpinifolia	31	53	77	9, 5	6, 5	Qf; Qr; Qc	Ca; Um; Cb; Co
Coppice of deciduous oaks with Mediterranean scrub	32	288	81	7, 5	6	Qf; Qc ; Qr	Pp; Qs; Qcr; Qi; Pl; E; Ct; E; Cr; Mc
Forest of deciduous oaks	41	21	8	11	7, 5	Qc; Qr;	Um; Co; Fo; Pl
Forest of deciduous oaks and Ostrya carpinifolia	42	512	37	9, 5	6	Qf; Qr; Qc	Qi; Co; Qs; Qcr; Pp; Cb; Um; Fo; Pl
Forest of deciduous oaks and Mediterranean scrub	43	664	18	11, 5	4, 5	Qf; Qc; Qpt; Qp	P; Pl; Qs; Co; Qcr; Qi; Ln; Ac

Legend: Qp Quercus pubescens; Qf Quercus frainetto; Qr Quercus robur; Qc Quercus cerris; Qi Quercus ilex; Qcr Quercus crenata; Qs Qurcus suber; Co Carpinus orientalis; Pp Pinus pinea; Cb Carpinus betulus; Um Ulmus minor; Fo Fraxinus oxycarpa; Pl Phillyrea latifolia; Qpt Qurercus petraea; Ln Laurus nobilis; Ac Acer campestre; E Erica spp.; Cr Crataegus spp.; Mc Myrtus communis

Using this information, we have separated the dominant layer from the dominated forest layer, reclassifying the CHM LiDAR data for each FP, Table 1 shows the main forest structures of the analyzed FPs.

In this way, we obtained a binary layer that represents the dominant position of the forest characterized by evergreen and deciduous oaks. In Table 1 the main silvicultural parameters are shown for the eight forest structures analyzed [28].

Finally, to remove evergreen canopy trees from our analysis, represented by evergreen oaks and stone pine, we compared the NDVI value detected for the winter and summer season using the 8 and 4 bands provided by Sentinel-2 data. The result of this methodology allowed us to obtain a grid mask relative to the canopy of the deciduous oak forest of Castelporziano.

The achievement of this georeferenced database was necessary considering the high spatial heterogeneity in terms of density of deciduous oaks at the FP scale as shown in Fig. 4.



Fig. 4. Castelporziano deciduous oak forest: examples of heterogeneous distribution of oak canopy cover detected at the forest parcel (FP) scale (white line). The green dots represent cells of the Sentinel-2 grid with presence of deciduous oak's canopy. (Colour figure online)

To arrange a monitoring program for assessing the risk related to the ongoing crown decline in Castelporziano, the forest health status has been investigated applying NDVI index in diachronic way from 2015 to present [29]. For this purpose, a georeferenced dataset of multispectral images referred to the month of July, has been acquired by Sentinel-2 from 2015 to present and, to investigate the historical trend concerning the NDVI index, a series of Landsat-5 historical data was used for the years 1989, 2000 and 2009 [30]. All the multispectral data, Sentinel-2 and Landsat-5, provided by Copernicus Open Access Hub (https://www.copernicus.eu/en), were analyzed only to the grid cells in which the presence of oak canopy had been previously detected. Figure 5 shows an example concerning the method used to determine the vegetative health condition of the deciduous oak forest using NDVI index with Sentinel-2 images. Obviously, by using the "mask" of the deciduous oak canopy, at the scale of the grid Sentinel (100 m2), the surface investigated with the Landsat data (resolution of 900 m2) is lower.

3 Results and Discussion

The preliminary results regarding the effect of fenced areas on natural renewal capability have showed a positive effect on natural renewal of deciduous oak forest. In SA-1 and SA-2, in fact, a substantial high number of acorns have sprouted while, in the same

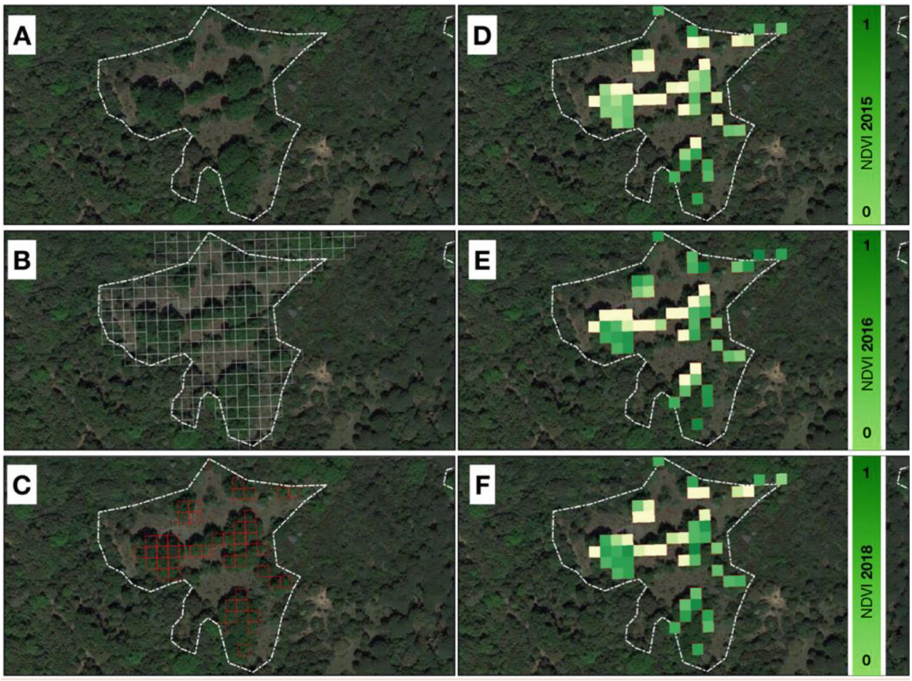
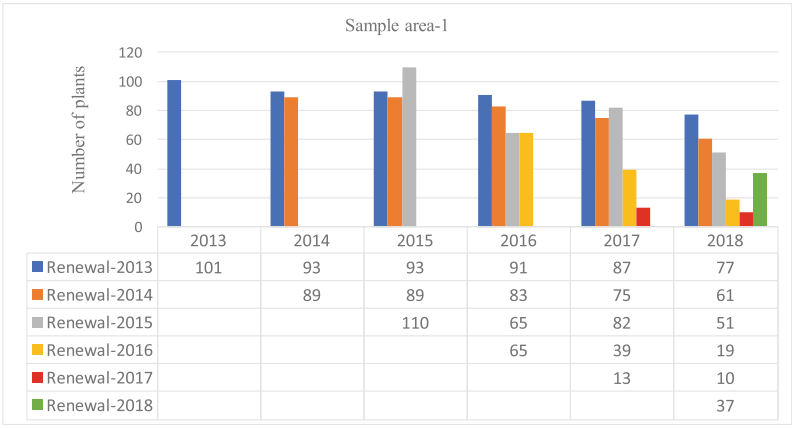


Fig. 5. (A) Forest Parcel (FP) (white line); (B) Sentinel-2 grid "mask"; (C) presence of oak deciduous canopy (red squares); (D, E and F) NDVI values detected for deciduous oak canopy for years: 2015, 2016 and 2017. (Colour figure online)

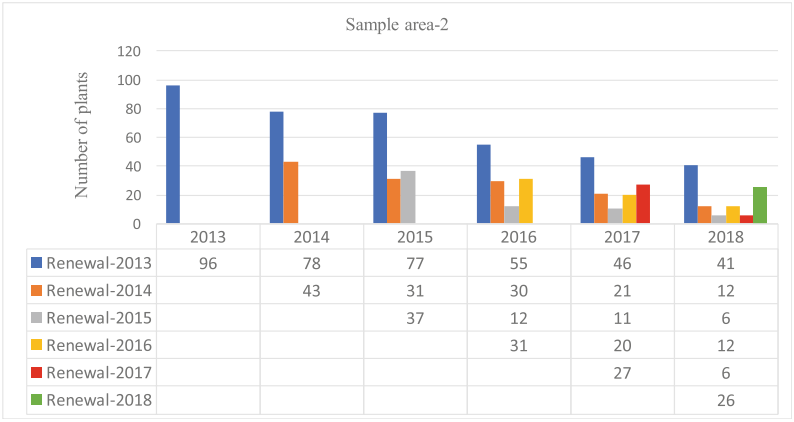
period, in the SA-3, not subject to forestry thinning, the effect of high density of the trees, the lack of light at the ground level and the competition for water availability due to the presence of high density of Mediterranean scrub, have played as limiting factor in natural renewing of the deciduous oak forest. Moreover, for the non-treated SA the seedlings of each year have presented a vegetative vigor not longer than three years that demonstrates how the high density of dominated layer of the forest does not allows a natural renewal of deciduous oak.

Concerning the effect of the different silvicoltural treatments carried out, comparing the two sample areas, it is clear that in SA-1 the response of natural renewal, in terms of oak seeds sprouting, is better than in SA-2 one as shown in Fig. 6. In fact, the number of annual seedlings, counted year by year, have showed a different mortality rate in the observed period. The SA-1, reduced by the 70% of its volume in 2013, presents a better micro climatic condition in terms of light and soil moisture available for the natural renewal and, for the same reason, the trees density rate produces a limiting factor in the introduction of other species such as those referred to the Mediterranean scrub.

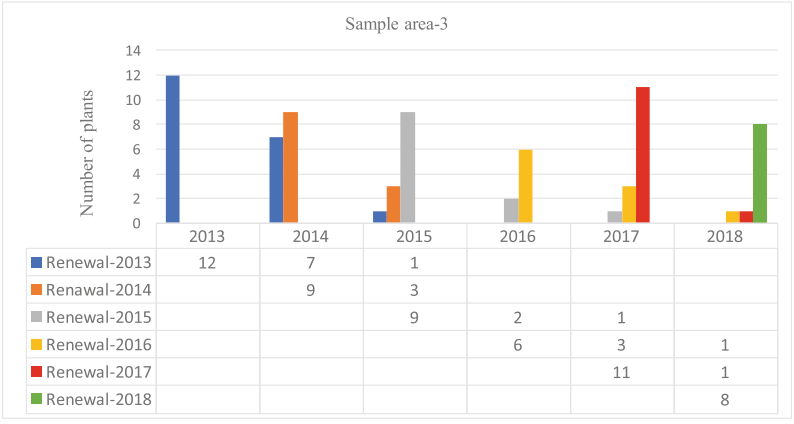
Regarding the monitoring system carried out with Sentinel-2 images and based on the specifically application of the NDVI index on deciduous oak canopy, a diffuse decline was detected from 2015 to 2018, as Fig. 7 shows. For these time series data, in fact, the



	2013	2014	2015	2016	2017	2018
Renewal-2013	101	93	93	91	87	77
Renewal-2014		89	89	83	75	61
Renewal-2015			110	65	82	51
Renewal-2016				65	39	19
Renewal-2017					13	10
Renewal-2018						37



	2013	2014	2015	2016	2017	2018
Renewal-2013	96	78	77	55	46	41
Renewal-2014		43	31	30	21	12
Renewal-2015			37	12	11	6
Renewal-2016				31	20	12
Renewal-2017					27	6
Renewal-2018						26



	2013	2014	2015	2016	2017	2018
Renewal-2013	12	7	1			
Renawal-2014		9	3			
Renewal-2015			9	2	1	
Renewal-2016				6	3	1
Renewal-2017					11	1
Renewal-2018						8

Fig. 6. Number of seedlings and mortality rate in the sample area (SA): 1, 2 and 3 for the period 2013-2018.

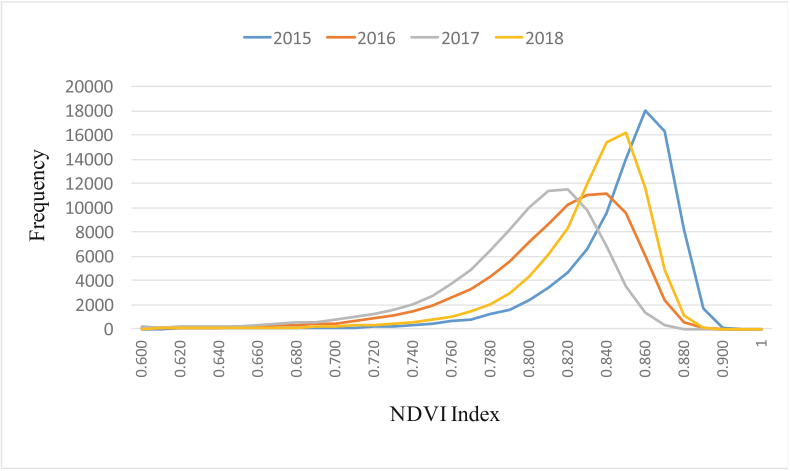


Fig. 7. NDVI index detected by Sentinel-2 satellite images (Years: 2015, 2016, 2017 and 2018).

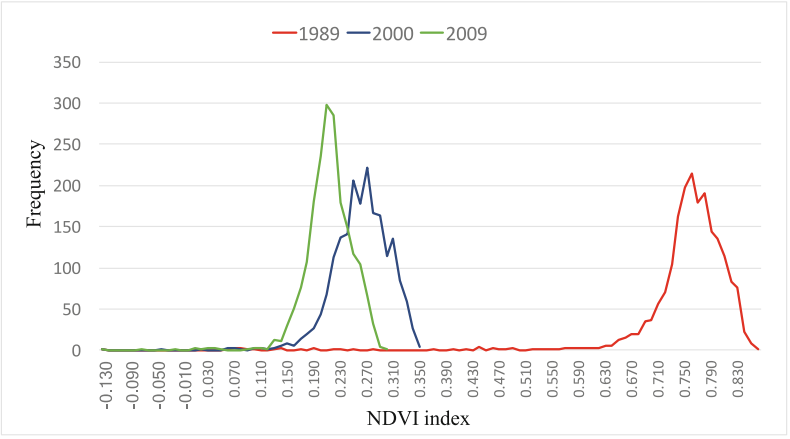


Fig. 8. NDVI index detected by Landsat-5 satellite images (Years: 1989, 2000 and 2009). Data refers to the 37% of the oak's canopy "mask" surface.

modal value of about 0.9 recorded in 2015 decline considerably for the years 2016 and 2018 with a minimum NDVI modal value recorded in 2017 of about 0.7.

Given the limited time series available when using Sentinel-2 multispectral images, further analysis was performed with Landsat-5 images to better understand the ongoing decline process. For this purpose, the availability of the data acquired since the late 80 s has allowed a more in-depth analysis of the trend of the state of vegetative vigor over time, shown in Fig. 8. Also for historical data on vegetative vigor, a widespread and progressive decline in the conditions of deciduous oak forests is confirmed. Referring to the modal values, it appears clear that from the end of the 80 s to 2009 there was a significantly reduction in NDVI modal values that from 0.77 in 1989 decreased until 0.21

in 2009. Although is not possible to directly compare the NDVI index values analyzed by Landsat-5 and Sentinel-2 data, because of their difference in the width of the spectral bands, results show that in the last thirty years the trend in vegetative health conditions of the studied area getting worse significantly.

4 Conclusion

The dieback of oak forest stands in the Mediterranean environment is today a very important topic within the scientific community. Especially for protected areas located in urban and peri-urban areas, these environments must be preserved with versatile and efficient analysis tools for the implementation of forest management operations.

In this research, we report the preliminary results from the application of different silvicultural treatments to facilitate the natural renewal of a protected forest. To monitor vegetation decline, a multispectral images dataset was created using Sentinel-2 and Landsat-5 satellites.

Census of seedlings carried out in the three sample areas showed that the competition for the light and soil moisture represent a limiting factor to natural renewal. Where the thinning (SA-3) of the forest has not been performed, the species of the dominated forest stand do not allow light to reach the ground, thus preventing seedlings from surviving.

In contrast, in the areas subjected to silvicultural treatment through the thinning of the dominated plan of the forest, the natural production of seedlings has been favored. In particular, the SA-1 was found to be the most efficient and this probably depends on a better density of plants compared to SA-2 where, the removal of 90% of the dominated layer, has favored the spread of the Mediterranean scrub limiting the development of oak seedlings over time.

Undoubtedly, the acquired data must be implemented over time to shed light on the ongoing process. Overall, the data acquired are intended to provide helpful specific indications for forest planning strategies of the protected area.

The monitoring of ongoing health decline based on remote sensing of multispectral images according to NDVI index is an effective tool that, thanks to the high frequency of acquisition offered by Sentinel-2, allows a monitoring concerning vegetative conditions, In addition, the arrangement of a grid layer “mask”, relative to the presence/absence of oak canopy enables accurate analysis that, given the spatial heterogeneity of the plants in the Mediterranean environment, becomes an unavoidable operation to build up accurate and effective information at the scale of the forest particle.

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Conflicts of Interest. The authors declare no conflict of interest.

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References

1. Millennium Ecosystem Assessment. Ecosystems and human well-being: Synthesis. Island Press, Washington, DC (2005) (ISBN 1–59726-040-1)
2. FAO and Plan Bleu. State of Mediterranean Forests 2018. Food and Agriculture Organization of the United Nations, Rome and Plan Bleu, Marseille (2018) ISBN FAO: 978-92-5-131047-2
3. Acacio, V., Holmgren, M., Rego, F., Moreira, F., Nohren, G.: Are drought and wildfires turning Mediterranean cork oak forest into persistent shrublands? Agroforestry Syst. **76**, 389–400 (2009)
4. Di Filippo, A., et al.: Climate change and oak growth decline: Dendroecology and stand productivity of a Turkey oak (Quercus cerris L.) old stored coppice in Central Italy. Ann. For. Sci. **67**, 706–710 (2010). https://doi.org/10.1051/forest/2010031
5. Gentilesca, T., et al.: Drought-induced oak decline in the western Mediterranean region: An overview on current evidences, mechanisms and management options to improve forest resilience. iForest Biogeosci. For. **10**, 796–806 (2014)
6. Colangelo, M., et al.: A multy proxy assessment of dieback causes in a Mediterranean oak species. Tree Physiol. **37**, 617–631 (2017)
7. Food and Agriculture Organization of the United Nations (FAO). Decline and Dieback of Trees and Forest; FAO Forestry Paper; FAO: Rome, Italy 1994
8. Natalini, F., Alejano, R., Vázquez-Piqué, J., Canellas, I., Gea-Izquierdo, G.: The role of climate change in the widespread mortality of holm oak in open woodlands of Southwestern Spain. Dendrochronologia **38**, 51–60 (2016)
9. Conte, A.L., et al.: Oak decline in the mediterranean basin: a study case from the southern apennines (Italy). Plant Sociol. **56**, 69–80 (2019). https://doi.org/10.7338/pls2019562/05
10. Di Filippo, A.: Climate change and oak growth decline: dendroecology and stand productivity of a turkey oak (Quercus cerris L.) old stored coppice in central italy. Ann. For. Sci. **67**, 1–14 (2010)
11. Costa, A., Pereira, H., Madeira, M.: Analysis of spatial pattern of oak decline in cork oak woodland in Mediterranean conditions. Ann. For. Sci. **204**, 16–26 (2010)
12. Manes, F., Seufert, G., Vitale, M.: Ecophysiological studies of Mediterranean plant species at the Castelporziano Estate. Atmos. Environ. **13**, 51–60 (2010)
13. Romagnoli, M., et al.: Climate factors and oak decline based on tree-ring analysis. a case study of peri-urban forest in the Mediterranean area. Urban For. Urban Gree. **34**, 17–28 (2018)
14. Maselli, F.: Monitoring forest conditions in a protected Mediterranean coastal area by the analysis of multiyear NDVI data. Remote Sens. Environ. **89**, 423–433 (2004)
15. Modica, G., et al.: Using landsat 8 imagery in detecting cork oak (Quercus suber L.) woodlands: a case study in Calabria (Italy). J. Agric. Eng. **47**, 205–215 (2016)
16. Bannari, A., Morin, D., Bonn, F.: A review of vegetation indices. Remote Sens. Rev. **13**, 95–120 (1995)
17. Ogaya, R., Barbeta, A., Başnou, C., Peñuelas, J.: Satellite data as indicators of tree biomass growth and forest dieback in a Mediterranean holm oak forest. Ann. For. Sci. **72**(1), 135–144 (2014). https://doi.org/10.1007/s13595-014-0408-y
18. Korhonen, L., Petteri, P.K., Rautiainen, M.: Comparison of Sentinel-2 and Landsat 8 in the estimation of boreal forest canopy cover and leaf area index. Remote Sens. Env. **195**, 259–274 (2017)
19. Haeusler, T., Enble, F., Gomez, S.: Satellite based monitoring of forest resources compliant with red + and zero deforestation. Responsible land governance: Towards an evidence based approach. Annual World Bank Conference and Poverty. Washington DC, March 20–24 (2017)
20. Recanatesi, F., Tolli, M., Ripa, M.N., Pelorosso, R., Gobattoni, F., Leone, A.: Detection of landscape patterns in airborne LIDAR data in the nature reserve of Castelporziano (Rome). J. Agric. Eng. **44**, 472–477 (2013)

21. Recanatesi, F.: Variation in land use/ land cover changes (LULCCs) in a peri-urban Mediterranean nature reserve: the estate of Castelporziano (Rome). Rendiconti Lincei **26**, 517–526 (2015)
22. Bianco, P.M., Martelli, F., Pignatti, S.: Clima. In: La Vegetazione Della Tenuta Presidenziale Di Castelporziano. Accademia Nazionale delle Scienze, pp. 453–455 (2001)
23. Giordano, E., Capitoni, B., Eberle, A., Maffei, L., Musicanti, A., Recanatesi, F., Torri, V.: Piano di gestione forestale della tenuta presidenziale di castelporziano [forest management plan of the presidential estate of castelporziano]. Segretariato Generale della Presidenza della Repubblica-Commissione Tecnico-Scientifica della Tenuta Presidenziale di Castelporziano **3**, 131–398 (2006)
24. Scrinzi, G., Presutti Saba, E., Colle, G.: Accademia Nazionale delle Scienze. Indirizzi Gestionali E Obiettivi D'intervento Per Le Classi Colturali Della Foresta Della Tenuta Presidenziale Di Castelporziano. Roma, Italy (2016)
25. Focardi, S., et al.: Monitoring populations of a guild of ungulates: implications for the conservation of a relict Mediterranean forest. Rendiconti Lincei **26**(3), 535–544 (2015). https://doi.org/10.1007/s12210-015-0439-9
26. Fanelli, G., Tescarollo, P.: The reneval of deciduous arboreous species in Castelporziano. Ricerche sulla complessità di un ecosistema forestale costiero mediterraneo. Scritti e documenti XXXVII, Seconda Serie Vol. II. Accademia Nazionale delle Scienze, pp. 607–622 (2006)
27. Recanatesi, F., Giuliani, C., Rossi, C.M., Ripa, M.N.: A remote sensing-assisted risk rating study to monitor pinewood forest decline: the study case of the Castelporziano state nature reserve (Rome). Smart Innov. Syst. Technol. **100**, 68–75 (2018)
28. Recanatesi, F., Giuliani, C., Ripa, M.N.: Monitoring mediterranean oak decline in a peri-urban protected area using ndvi and sentinel-2 images: the case study of Castelporziano state natural reserve. Sustainability **10**, 1–10 (2018)
29. Chiesi, M., et al.: Integration of ground and satellite data to model Mediterranean forest processes. Int. J. Appl. Earth obs. Geoinf. **13**, 504–515 (2011)
30. Deshayes, M., et al.: The contribution of remote sensing to the assessment of drought effects in forest ecosystems. Ann. For. Sci. **63**, 579–595 (2006). https://doi.org/10.1051/forest:2006045