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Research paper

The role of dominant tree cover and silvicultural practices on the post-fire recovery of Mediterranean afforestations

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Abstract - Fire is one of the major disturbance factors in Mediterranean-type ecosystems, where since long time man has deeply modified the natural fire regime. To know how woody species recover after fire is of prominent importance for understanding vegetation dynamics, as well as for the management of Mediterranean plantations, especially where broadleaved and coniferous trees coexist. Our research was carried out at Monte Petroso (Sicily), within an historical afforestation intervention in the Mediterranean basin. We assessed the post-fire response of mixed oaks and oak-pine afforestations within six experimental plots (two plots per homogeneous sector) differing in dominant tree species (*Quercus ilex* or *Pinus pinea*), time since last wildfire (1954 or 1982), and post-fire management (understory cleaning and removal of dead biomass or no management). Dendrometric surveys and phytosociological relevés were carried out to characterize the tree layers, the regeneration by woody species plus *Ampelodesmos mauritanicus*, as well as plant species richness. Our field surveys have confirmed a notably high resilience to fire by Mediterranean woody species, regardless of post-fire management practices. The dominant tree species played a significant role as *Quercus ilex* seems to foster stand development and the regeneration dynamics in the understory, especially that of *Quercus pubescens*. By contrast, *Pinus pinea* seems to slow down the regeneration by woody species, especially at higher stand density. Post-fire management practices seemed to favor mantle shrubs (*Prunetalia spinosae*) and grassland species (*Hyparrhenietalia hirtae*), while negatively affecting shrub species (*Cisto-Ericetalia multiflorae*). In presence of sufficient propagules of native woody species, the option of no management after fire has to be considered. The results of our research may be useful to improve the management of fire-prone Mediterranean plantations, taking into account the differences in plant strategies to cope with fire, as well as the dominant canopy.

Keywords - *Quercus* spp.; *Pinus pinea*; regeneration; forest management; vegetation dynamics

Introduction

Fire plays a prominent role in shaping Mediterranean plant communities (Bengtsson et al. 2000, Lloret et al. 2002, García-Jiménez et al. 2017). Its millennial selective pressure induced in Mediterranean plants a considerable resilience to it (Buhk et al. 2006, Keeley et al. 2011), i.e. a great ability to return to a pre-disturbance state (Hanes 1971, Trabaud and Galtié 1996, Moya et al. 2011). Mediterranean woody species may adopt two main strategies to cope with fire: sprouting and seeding (Keeley and Zedler 1978, Calvo et al. 2003). Species such as *Cistus* spp. and *Rhamnus alaternus* L. are seeders, as they increase germination after fire passage, thus implying the existence of a resistant soil seed bank (Crosti et al. 2006). Other species such as thermophilous oaks (*Quercus coccifera* L., *Quercus ilex* L. and *Quercus pubescens* Willd.) and *Erica* spp. are resprouters, responding to fire through the emission of new shoots, either by roots, by stumps or by damaged stems (Buhk et al. 2006, Pausas 2006, Moreira et al. 2013). Despite both strategies may coexist in the same woody species, one strategy tends to prevail over the other (Kazanis and Arianoutsou 2004). The Mediterranean conifers do not resprout after a disturbance event, thus exclusively relying on sexual reproduction and seed traits (Díaz-Delgado et al. 2002, Pausas et al. 2008, García-Jiménez et al. 2017). Serotinous pines such as *Pinus halepensis* Mill. and *Pinus pinaster* Aiton are particularly favoured by fire (Moreira et al. 2012), while non-serotinous pines such as *Pinus nigra* J.F. Arnold and *Pinus sylvestris* L. lack of specific adaptations to fire (Retana et al. 2012). *Pinus pinea* L., despite not bearing serotinous cones, yet it has hard-coated seeds and thick bark giving it a good resistance to fire passage and some post-fire natural regeneration (Escudero et al. 1999). The response of both seeders and resprouters is severely hindered when fire frequency exceeds some threshold, and large differences among these functional groups, as well as among woody species exist (Pausas 2006). *Pinus* spp. are known to be more negatively affected by and less resilient to short-interval recurrent fires than *Quercus* spp. (Pausas et al. 2008, Vallejo and Alloza 2012). Within oaks, broadleaved species are characterized by slower recovery time after fire than

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evergreen species, requiring even more than 50-60 years (Trabaud and Galtié 1996, Moreira et al. 2011). Evergreen-sclerophyllous species have an inherent higher ability to overcome post-fire limiting stressful conditions (e.g.: water stress due to irradiance) (Espelta et al. 2012).

The effective recovery after fire is also strongly dependent on wildfire characteristics, such as type, frequency, intensity and seasonality, which all play a crucial role on forest stand dynamics and tree species response (Bellingham and Sparrow 2000, Corona et al. 2015). The frequency of the disturbance has large effects on landscape traits (Trabaud and Galtié 1996, Moreira et al. 2011, Guiomar et al. 2015), as well as on the structure and composition of plant communities (Pausas 2006, Espelta et al. 2008). Wildfires with moderate intensity and low frequency may exert a positive effect on biodiversity in the Mediterranean basin (Maggiore et al. 2005), and may also accelerate the renaturalization process of plantations, fostering the development of complex, more species-rich and stable forest stands, dominated by native broadleaved species (Curt et al. 2009, Badalamenti et al. 2017, 2018). By contrast, the landscape homogenization, the reduction of the resilience of forest stands, and a prevalence of shrub species over tree species generally result from increased fire frequencies (Díaz-Delgado et al. 2002, Moreira et al. 2011). Since ancient times man has changed the natural fire regime in the Mediterranean basin, increasing its frequency, intensity and potential fuel loads (Moreira et al. 2012, San-Miguel-Ayanz et al. 2013). Within Mediterranean plantations the lack of specific fuels treatments or of understory management has significantly enhanced the potential fuel load and continuity, increasing potential fire severity (Corona et al. 2015). As increasingly frequent and intense fire events are expected in the Mediterranean basin (Moreira et al. 2013), to know how woody species respond to fire is of primary importance to understand the evolution of Mediterranean vegetation, as well as for improving the management of fire-prone Mediterranean plantations. After the massive afforestation interventions carried out throughout the Mediterranean basin during the last century, large areas are now covered with artificial plantations (Pausas et al. 2004, Maetzke et al. 2017), mainly dominated by introduced Pines and Eucalypts (Moreira et al. 2013, Rühl et al. 2015). Such tree species were mainly chosen with the aim to increase forest cover, to provide effective defence against soil erosion and to stabilize unstable and degraded slopes (Pausas et al. 2004, Corona et al. 2009, Rühl et al. 2015), due to their pioneer character (e.g.: initial fast growth rates), limited ecological requirements as well as easy propagation. Native woody species were seldom used. The large preference accorded to non-native woody species has led to the formation of simplified forest stands in the Mediterranean basin, with low overall biodiversity (Granados et al. 2016). However, renaturalization processes by native woody species have been increasingly observed within many Mediterranean afforestations, that were gradually converted into multilayered and complex mixed pine-oak forests (Sheffer 2012). As concerns fire, this has further complicated the overall picture. In fact, as said before, pines and oaks adopt different strategies to cope with fire (Granados et al. 2016). In recent years, the knowledge of post-fire vegetation dynamics and management in the Mediterranean basin has greatly increased (Buhk et al. 2006, Moreira et al. 2012). Many recent studies have underlined the role played by post-fire management practices on the recovery ability of different biological communities (Bros et al. 2011, Rollan and Real 2011), including plants (Moreira et al. 2012). However, field investigations about the effects of fire on plant species richness and regeneration by woody species of mixed plantations are relatively scarce in the Mediterranean basin (Curt et al. 2009). Mediterranean plantations are frequently affected by wildfires and their response to such disturbance factor is of crucial importance for an effective management. Furthermore, such simplified forest ecosystems include both seeders and resprouters, so that their after fire is quite unpredictable and needs to be experimentally tested (Bellingham and Sparrow 2000). To increase our knowledge of such fire-prone and quite heterogeneous Mediterranean forest ecosystems, we assessed the long-term post-fire response of mixed plantations in areas differing in post-fire treatments (understory management vs. no management), time since last wildfire occurrence (1954 or 1982) and dominant tree species (*Quercus ilex* or *Pinus pinea)*. More in detail, we aimed at assessing the role of dominant tree species and post-fire forest interventions in post-fire recovery of woody species in Mediterranean afforestations. We believe our results contribute in increasing knowledge about post-fire vegetation response in the Mediterranean basin in order to better manage afforested areas prone to frequent wildfires.

Material and methods

Study site

The study was carried out at "*Monte Petroso*", (663 m a.s.l.) located about 3 Km from Palermo city, on the Western sector of Palermo plain (Sicily) (Fig. 1). Dolomitic limestone is the most common outcropping rock (Abate et al. 1982), while the dominant soil association includes Lithic Xerorthens,

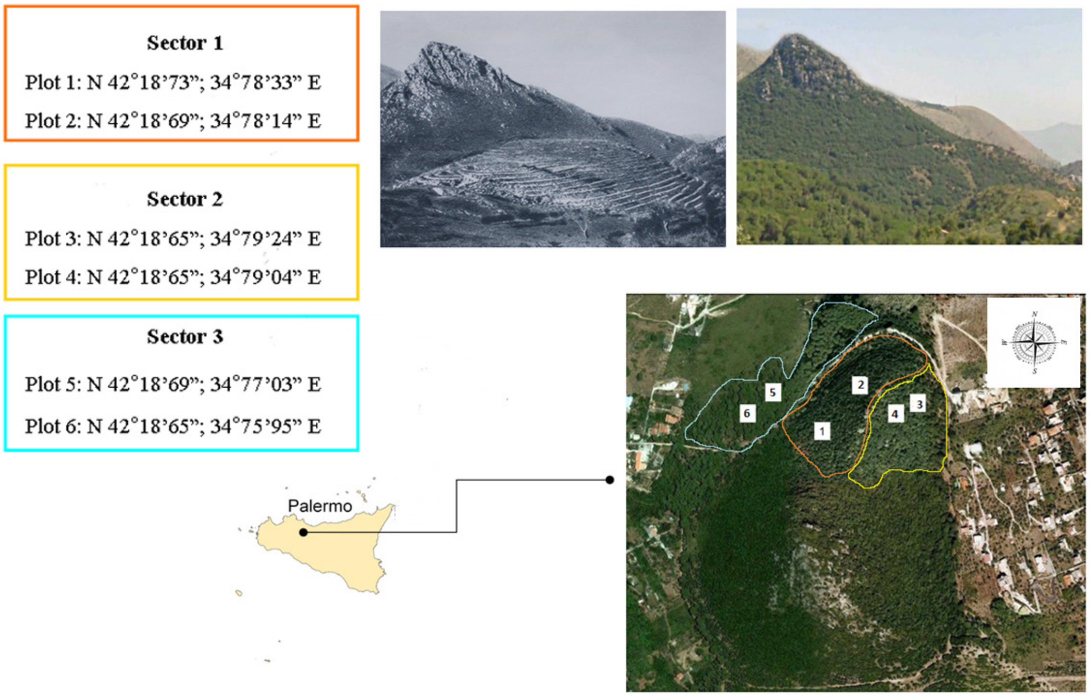

Figure 1 - Location of the study area (Mt. Petroso). Numbers from 1 to 6 show the location of the sampling plots. The picture on the center of upper part was taken in 1934 and shows the SW slopes, while the picture on the upper right corner shows the S-SW slopes.

Rock Outcrop, Typic and Lithic Rhodoxeralfs (Fierotti 1988). According to Rivas-Martínez (2008), the study area falls within the thermo-Mediterranean bioclimatic belt.

The reforestation of Mt. Petroso, extending on approx. 54 hectares (Troía et al. 2011), is a very well documented case study in the Mediterranean. The afforestation techniques adopted have a remarkable historical value (AA. VV. 1943), representing a paradigmatic case for the whole biogeographic area. A photo taken in 1934, illustrating the ongoing forest interventions, is reported under the word "rimboschimento" (= afforestation) within an Italian Encyclopaedia (AA. VV. 1943). All the slopes of Monte Petroso were reforested with native oak species (*Quercus ilex*, *Q. pubescens* and *Q. suber*) and manna ash (*Fraxinus ornus* L.), while locally non-native conifers (*Pinus pinea*, *P. halepensis* and *Cupressus sempervirens* L.) were mainly planted at low-altitude slopes. Mixed forest stands and afforestations are found between 500 and 600 m a.s.l., while above 600 m the slopes are covered by native tree species, which survived on rocky cliffs and crevices. Further details on the vascular flora and vegetation of Mt. Petroso are given by Troìa et al. (2011).

Selection and characteristics of the sampling plots

Before investigating the vegetation response, a preliminary analysis was carried out by means of aerial photos coming from the archives of the Italian Military Geographical Institute, dating back to October 1954 and June 1968, and from the archives of the Agriculture and Forest Office of Sicilian regional government, dating back to June 1978, June 1987 and October 1997. Information provided by photo interpretation suggested us to split the overall study area (Mt. Petroso) into three homogeneous sectors, according to the main forest types and time since last wildfire. Then, through dedicated field surveys, we validated the classification of the three main sectors obtained from photointerpretation. The first sector includes the northern and northwestern slopes which suffered wildfire in 1982. The second sector includes the northeastern slopes, burned in 1954 but spared by flames in 1982. In both sectors a mixed oaks forest with *Quercus ilex* as dominant tree species is present. The third sector includes stone pine forests subject to the fire of 1982, which destroyed the shrub and the herb layers, without significantly affecting the dominant tree layer. Two plots have been established within each sector, for a total of six sampling plots (Table 1). It was possible to consider small sample size (2 plots x 3 sectors) due to the relatively homogeneous conditions of the forest stands within each sector. The investigated plots mainly differ in terms of dominant tree species (*Quercus ilex* or *Pinus pinea*), time since last wildfire (1954 or 1982), and post-fire management practices, including understory cleaning and removal of dead biomass every two years in managed plots and no intervention in unmanaged plots. The aerial photos were also used to verify that no other wildfire has occurred in the investigated plots after 1954 and 1982, respectively. As we learned from interviews to local foresters and forest workers,

Table 1 - Overview of the main physical and silvicultural characteristics of sampling plots.

Parameter	Sector (Plot)					
	1 (1)	1 (2)	2 (3)	2 (4)	3 (5)	3 (6)
Altitude (m a.s.l.)	525	525	485	525	480	500
Slope (°)	27	16	25	30	0	6
Aspect	NW	N	NE	NE	flat	SE
Stone outcrop (%)	< 30	< 30	< 30	< 30	< 5	< 30
Rock outcrop (%)	~50	~50	~50	~50	< 5	< 5
Year since last wildfire	1982	1982	1954	1954	1982	1982
Dominating tree species	*Q. ilex*	*Q. ilex*	*Q. ilex*	*Q. ilex*	*P. pinea*	*P. pinea*
After fire understory management	every two years	none	every two years	none	every two years	none

post-fire management practices started soon after the fire passage, both in 1954 and 1982, and were regularly carried out every two years until spring 2005, when the field surveys were carried out.

Sampling method, dendrometric, regeneration and floristic surveys

Forest resources were sampled using a simplified version of MNTFR (Monitoring of Non-Timber Forest Resources), as proposed by Rühl et al. (2005). Field surveys were carried out within a circular sampling plot of about 450 m^2 (radius = 12 m). Plots from 1 to 4 are dominated by *Quercus* spp., mainly holm oak, whereas stone pine is the dominant species within plots 5 and 6. For each tree species, the following dendrometric parameters have been assessed: density, diameter at breast height (DBH), total height and crown height, crown projection along the four cardinal directions, plant position according to a Cartesian-coordinate system, whose centre is one of the sampling plot borders (Table 2).

Phytosociological relevés according to Braun-Blanquet (1964) were performed within a circular subplot having the same centre of the main plot and an area of about 200 m^2 (radius = 8 m). The plot size is in line with other studies on the response of Mediterranean vegetation after fire (e.g.: Álvarez et al. 2009, Tessler et al. 2016). Plant nomenclature follows Pignatti (1982), Conti et al. (2005) and Raimondo et al. (2010). Regeneration and shrub layer were assessed in the same subplots, assessing density, basal diameter and total height (Table 3). *Ampelodesmos mauritanicus* (Poir.) T. Dur. & Schinz (hereafter *Ampelodesmos*), a widespread native perennial grass, was also included in the field investigations for its recognized importance for understanding Mediterranean vegetation dynamics after fire (Incerti et al. 2013). For this grass species we considered the tussock basal diameter, as assessed in other grass species (e.g.: Yu et al. 2011). In order to provide a spatial representation of the vegetation structure within the selected plots, the software SVS (Stand Visualisation System) 3.30 (McGaughey 1997) was used. From a phytosociological point of view, the investigated vegetation is referred to the class *Quercetea ilicis* Br.-Bl. ex A. & O. de Bolòs 1947, order *Quercetalia ilicis* Br.-Bl. ex Molinier 1934 em. Rivas-Mart. 1975, and alliance *Quercion ilicis* Br.-Bl. ex Molinier 1934 em. Brullo, Di Martino & Marcenò 1977 (Brullo et al. 2009).

Results

Dendrometric surveys

Dendrometric data for the dominant tree layer are provided in Table 2, whereas data for regeneration layers, including trees, as well as shrubs plus *Ampelodesmos* are provided in Tables 3 and 4, respectively. The structural representation of the investigated plots is reported in figure 2.

Table 2 - Dendrometric parameters of the dominant tree species within the investigated plots.

Sector (Plot)	Woody species	Frequency (%)	Stumps ($N\ ha^{-1}$)	Coppice shoots ($N\ ha^{-1}$)	Stems ($N\ ha^{-1}$)	DBH (cm)	Total height (m)	Crown height (m)	Crown cover (m^2)	Basal area ($m^2\ ha^{-1}$)
1 (1)	*Quercus ilex*[2]	89.9	995	3'736	-	7.17	6.65	2.86	2.36	16.11
	Quercus pubescens[2]	8.0	133	332	-	9.56	6.95	4.28	2.48	2.60
	Quercus suber[2]	2.1	-	-	88	8.50	5.05	2.58	0.85	0.60
1 (2)	*Fraxinus ornus*	20.0	177	1'238	-	3.75	3.79	1.51	0.44	1.60
	Quercus ilex[2]	64.3	796	3'979	-	4.12	2.74	0.75	1.11	7.83
	Quercus pubescens[2]	8.6	88	531	-	14.67	4.80	1.77	6.36	9.66
2 (3)	*Quercus ilex*[2]	72.4	442	1'857	-	8.81	7.66	2.28	3.20	13.20
	Quercus pubescens[2]	6.9	-	-	177	28.00	7.90	2.80	23.35	10.90
	Quercus suber[2]	20.7	88	531	-	21.67	6.18	2.13	12.80	22.80
2 (4)	*Quercus ilex*[2]	97.1	1'680	5'924	-	4.13	3.49	0.99	2.45	22.94
	Quercus pubescens[2]	2.9	-	-	177	15.00	8.75	4.00	10.47	3.14
3 (5)	*Pinus pinea*[1]	6.7	-	-	531	36.67	17.35	14.68	62.57	57.42
	Quercus ilex[2]	91.1	2'299	7'250	-	3.51	3.28	0.82	1.15	8.55
3 (6)	*Pinus pinea*[1]	41.2	-	-	619	27.21	13.93	8.93	31.45	36.33
	Quercus ilex[2]	58.8	265	884	-	3.55	3.37	0.83	2.05	0.95

[1]Only planted; [2]Mostly planted

Table 3 - Density and dendrometric parameters of the tree regeneration layer.

Sector (Plot)	Species	Density (N ha^{-1})	Basal diameter (cm)	Height (m)
1 (1)	*Quercus ilex*	2'403	0.75	0.42
	Quercus pubescens	420	0.79	0.23
	Quercus suber	44	0.70	0.30
	Rhamnus alaternus	66	2.55	0.50
1 (2)	*Quercus ilex*	1'238	2.25	1.39
	Quercus pubescens	1'149	1.02	0.95
	Fraxinus ornus	88	0.80	0.80
	Rhamnus alaternus	619	2.86	1.49
2 (3)	*Quercus ilex*	19'983	1.39	0.84
	Quercus pubescens	2'299	0.23	0.08
	Rhamnus alaternus	265	1.45	0.57
2 (4)	*Quercus ilex*	6'366	0.83	0.76
	Quercus pubescens	88	0.50	0.40
3 (5)	*Quercus ilex*	2'653	0.34	0.28
	Quercus pubescens	796	0.28	0.18
3 (6)	*Quercus ilex*	1'592	0.73	0.86
	Quercus pubescens	88	0.50	0.60
	Rhamnus alaternus	707	1.58	0.57

Table 4 - Density and dendrometric parameters of the shrub layer plus *Ampelodesmos*.

Sector (Plot)	Species	Density (N ha^{-1})	Basal diameter (cm)	Height (m)
1 (1)	*Ampelodesmos mauritanicus*	1'172	8.60	0.30
	Calicotome infesta	44	8.60	0.30
	Erica multiflora	155	3.10	0.29
1 (2)	*Cistus creticus*	2'387	1.78	0.40
	Emerus major subsp. *major*	2'299	5.00	1.22
	Spartium junceum	531	4.13	1.38
	Teucrium flavum	354	1.98	0.50
2 (3)	*Ampelodesmos mauritanicus*	3'095	10.20	0.44
	Calicotome infesta	442	2.70	0.74
	Cistus salviifolius	88	2.30	0.40
	Spartium junceum	442	4.82	1.20
	Teucrium flavum	177	1.65	0.40
2 (4)	*Ampelodesmos mauritanicus*	2'829	8.30	0.74
	Calicotome infesta	265	2.85	0.87
	Cistus salviifolius	88	2.30	0.40
	Teucrium flavum	1'061	1.95	0.67
	Teucrium fruticans	1'592	1.45	0.41
3 (5)	*Ampelodesmos mauritanicus*	3'979	5.35	0.30
	Cistus creticus	88	2.00	1.57
	Crataegus monogyna	531	2.58	1.50
3 (6)	*Ampelodesmos mauritanicus*	1'680	4.86	0.30
	Erica multiflora	4'244	2.00	0.80
	Teucrium flavum	884	2.00	0.80

Plot 1 is dominated by holm oak (frequency approaching 90%), with only few downy oak and cork oak individuals occurring in the tree layer. During 1982, a fire completely destroyed the tree layer. About 1'000 stumps with more than 3'700 coppice shoots per hectare of holm oak were found. Mean DBH for all tree species was 8.4 cm, while mean height was 6.2 m. The total basal area was 19.3 m^2 ha^{-1}. Holm oak regeneration was particularly abundant, exceeding 2'400 individuals per hectare. Such high value has also to be attributed to the limited occurrence and poor development of shrubs, which have been seriously damaged by the continuous understory cleaning practices. Only *Calicotome infesta* and *Erica multiflora* L. occur in the shrub layer both, all represented by a few individuals. *Ampelodesmos* regeneration is quite abundant, exceeding 1'000 individuals per hectare.

Plot 2 is still dominated by *Quercus ilex* (frequency of more than 60%), but *Q. pubescens* and *Fraxinus ornus* are also present in the plot, both with well established natural regeneration. However, about 800 stumps with almost 4'000 coppice shoots per hectare of holm oak were found. More than 1'200 coppice shoots of *Fraxinus* also occur *Q. pubescens* is less common in the dominant layer, yet it showed a natural regeneration as abundant as that of *Q. ilex*, both with more than 1'000 individuals per hectare. Mean DBH for all tree species was 7.5 cm, while mean height was 3.8 m. The total basal area was 19.1 m^2 ha^{-1}. However, the largest trees belong to *Q. pubescens*, this species reaching a mean DBH of almost 15 cm. The area is almost impenetrable because it is largely covered by shrubs such as *Cistus creticus* L. and *Emerus major* Mill. subsp. *major*, both quite abundant in terms of density and with large mean size.

Plot 3 is formed by a mixed oak forest stand dominated by *Quercus ilex* (frequency of more than 70%), followed by *Q. suber* (frequency of more than 20%) and *Q. pubescens* (frequency of about 7%), reaching a total tree cover of 80%. Holm oak regeneration was partially originated from the seeds produced by mature plants (density of almost 20'000 individuals per hectare), and partially from coppice shoots after coppicing (density of more than 1'800 coppice shoots per hectare). *Q. pubescens* showed a lower regeneration potential, with seedlings often

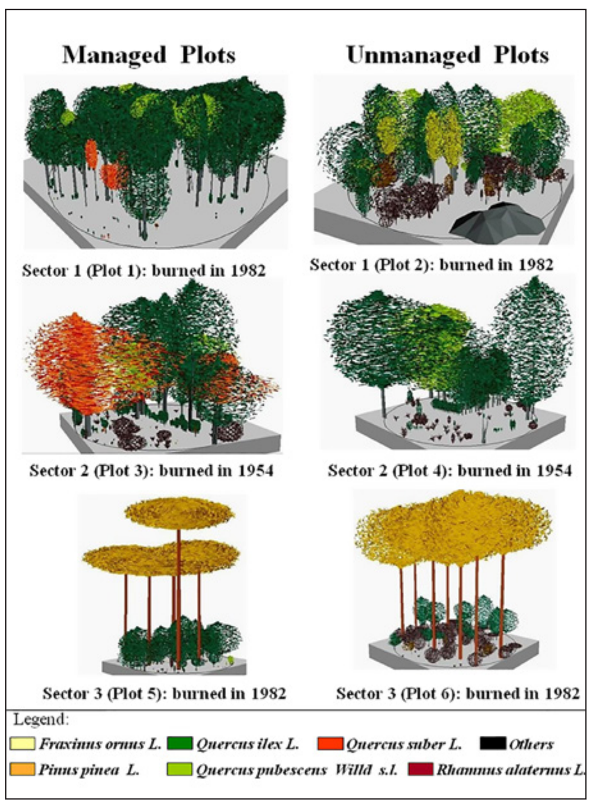

Figure 2 - Structural representation of the vegetation structure within the investigated plots.

not still established and with reduced size. Mean DBH was quite different among tree species, ranging from 8.8 cm by holm oak to 28.0 cm by cork oak. Downy oak reached a mean DBH of 21.7 cm. Mean height for all tree species was 7.2 m, while the total basal area was about 47 m^2 ha^{-1}. Despite the occurrence of four shrubs, the understory is largely covered by the dominant grass *Ampelodesmos*, exceeding 3'000 individuals per hectare.

Plot 4 is strongly dominated by *Quercus ilex* (frequency of about 97%), with only few *Q. pubescens* individuals. The tree regeneration layer is mainly formed by holm oak individuals, belonging to two different growth stages. The largest seedlings are concentrated along the edge of a terrace, where there are some burned stumps. The smallest seedlings can hardly stand out from the shrub layer. Because of the abundance of sprouts there is a strong competition among coppice shoots, being more than 6'000 individuals per hectare. Natural regeneration is widespread despite being mainly concentrated under the stone terraces and still characterized by poor development. Mean DBH ranged from 4.1 cm to 15.0 cm and mean height ranged from 3.5 m to 8.8 m in holm oak and downy oak, respectively. The total basal area was 26.1 m^2 ha^{-1}. Despite the tree layer reached a noteworthy cover of 70%, the shrub layer is well represented and mainly formed by *Teucrium flavum* L. and *Teucrium fruticans* L., together reaching a total cover of about 40% and both exceeding 1'000 individuals per hectare. *Ampelodesmos* is abundant as well, with more than 2'800 individuals per hectare.

Plot 5 shows a different structure of vegetation. Two main tree layers may be recognized: the dominant layer is formed by larger *Pinus pinea* individuals, which cover most of the plot area (density: 531 stems ha^{-1}), despite representing less than 7% of all the tree individuals. *Pinus* reached a mean DBH of 36.7 cm and a mean height of 17.4 m. After fire passage, no sign of natural regeneration by stone pine was observed, suggesting a very low regeneration performance. The dominated layer is composed by smaller holm oak individuals, having a mean DBH of 3.5 cm and a mean height of 3.3 m. The total basal area was 66.0 m^2 ha^{-1}. Despite the tree cover is 80%, it is possible to distinguish a third woody layer, formed by two shrubs (*Cistus creticus* and *Crataegus monogyna* Jacq.) and by a very recent regeneration by holm oak (more frequently) and downy oak. The understory is largely covered by the dominant grass *Ampelodesmos*, reaching almost 4'000 individuals per hectare.

Plot 6 is a stone pine forest with a more closed canopy, and a holm oak dominated layer. *Pinus pinea* individuals cover most of the plot area (density: 619 stems ha^{-1}), and reached a mean DBH of 27.2 cm and a mean height of 13.9 m. After fire passage, natural regeneration by stone pine was almost absent. The dominated layer is composed by smaller holm oak individuals, having a mean DBH of 3.6 cm and a mean height of 3.4 m. The total basal area was 37.3 m^2 ha^{-1}. The tree regeneration layer is mainly composed by holm oak, reaching about 1'600 individuals per hectare. The regeneration of holm oak, downy oak and *Rhamnus alaternus* has a gamic origin. The understory layer is mostly formed by an *Erica multiflora* L. open maquis with a cover of 60% and more than 4'000 individuals per hectare. The regeneration of *Ampelodesmos* is also abundant.

Table 5 - Synthesis of the phytosociological relevés carried out within the investigated plots.

	Sector (Plot)					
	1 (1)	1 (2)	2 (3)	2 (4)	3 (5)	3 (6)
Tree layer						
Cover (%)	50	60	80	70	80	70
Mean height (cm)	622	378	725	612	1032	865
Shrub layer						
Cover (%)	40	60	30	60	40	60
Mean height (cm)	30	85	60	65	170	120
Herb layer						
Cover (%)	40	50	30	20	30	15
Mean height (cm)	10	15	15	10	10	15
Total taxa	29	38	27	17	21	21
Planted species	0	0	0	0	1	1
char. *Quercetalia ilicis*	8	10	5	5	5	4
char. *Quercetalia calliprini*	4	7	5	5	3	2
char. *Cisto-Ericetalia multiflorae*	3	3	2	2	0	6
char. *Prunetalia spinosae*	2	3	2	0	3	0
char. *Hyparrhenietalia hirtae*	7	6	7	2	7	6
plants linked to rocky/stony habitats	1	4	2	2	1	1
other herbs and grasses	4	5	4	1	1	1

Species richness

A synthesis of the results of the phytosociological relevés is reported in Table 5 (full data are available in Annex). Overall, total species richness ranged from 17 (Sector 2, Plot 4) to 38 species (Sector 1, Plot 2), with a mean value of about 25 species. Within the first sector, a quite higher plant species richness was found in the unmanaged plot (38 vs 29), with a corresponding higher frequency and cover of pre-forest and forest woody species. Within the second sector, species richness was higher in the managed plot (27 vs 17), mainly due to the contribution of herbs, referred to the order *Hyparrhenietalia hirtae*, and of mantle shrubs, referred to the order *Prunetalia spinosae*. Both plots host the same number of pre-forest and forest woody species. The last sector includes the plots with the lowest number of species, both hosting 21 plant species, and more than half of them are herbs or shrubs. The managed plot hosts a slightly higher number of pre-forest and forest woody species.

Discussion

The post-fire response of Mediterranean plantations, assessed in terms of dominant tree canopy, woody species regeneration and plant species richness, was found to be affected by the dominant tree species and post-fire management strategies. Such aspects should be taken into account to understand the mechanisms underlying vegetation dynamics, as well as seedling regeneration and recruitment patterns in fire-prone Mediterranean afforested areas. Overall, field observations have confirmed the notable resilience by Mediterranean woody vegetation to fire.

Comparison plots burned in 1982

The comparison between plots 1-2 and 5-6, sharing the post-fire recovery time, allowed us to highlight the differential role of post-fire regeneration ability of dominant tree species and understory management on post-fire vegetation recovery, assessed in terms of structural development, establishment of natural regeneration, and species richness. In the holm oak stands burned in 1982 (Plot 1 vs Plot 2), the vegetation response of the unmanaged plot was positively influenced by the lack of active post-fire forest management. In spite of the time elapsed since the passage of the fire, notable differences were found according to different post-fire management practices. In the unmanaged plot, the dominance of holm oak was strongly reduced (from 90% to 64% in terms of density and from more than 80% to 41% in terms of basal area), and the relative contribution of other tree species has increased correspondingly. Holm oak individuals were more abundant, higher and larger in the managed plot, probably being favored in the interspecific competition with shrubs due to understory management. The abundance of holm oak regeneration also depended on its great resprouting ability from damaged stumps and/or roots after a disturbance event. The relative contribution of downy oak was by far higher in the unmanaged plot, despite the overall basal area was virtually the same in the two plots. Despite having the same number of stumps, the coppice shoots were much more numerous in the unmanaged plot (5’700 vs 4’000 per hectare). Similar levels of tree regeneration were found but tree individuals were much larger in the unmanaged plot, reaching an average height of 1 m, thus being definitely established. The unmanaged plot showed a higher structural complexity, arising from the higher cover of all the vegetation layers, from herb to tree. The upper layer is formed by thermophilous evergreen and deciduous trees, dominating a structurally complex shrub layer. This multilayered structure, providing a large micro-site variability, has favoured the natural regeneration by different woody species. The shrub layer was richer, with higher and well established individuals, in the unmanaged plot. The overall plant species richness was also higher, as well as the number of species related to pre-forest and forest habitats. As a consequence of the ongoing succession process, many species typical to pre-forest communities (*garrigue* and open *maquis*), such as *Emerus major* subsp. *major* and *Spartium junceum* L., but also several plant species linked with mature, closed and shady forest communities, have been found only in the unmanaged plot (Pasta 1993). The absence of post-fire interventions in the holm oak forest burned in 1982 has favored the compositional and structural evolution of the forest stand, which showed a high degree of resilience, resembling to a natural-like forest ecosystem. About 23 years after wildfire were sufficient for forest ecosystems to recover and to reach a near-steady state condition, thus allowing the entry of ornithochorous woody colonizers. Based on the published data on the vegetation of Mt. Petroso (Troìa 1994) and concerning local vegetation dynamics (La Mantia et al. 2002, Cullotta and Pasta 2004), the steady state is represented by mixed forest stands dominated by holm oak (*Quercus ilex*), where several deciduous broadleaved trees, such as *Acer campestre* L., *Quercus pubescens* and *Fraxinus ornus*, may co-occur. Such plant communities are framed into the phytosociological subassociation *Aceri campestris-Quercetum ilicis helleboretosum bocconei* (Brullo et al. 2009). After a few decades, in fact, forest stands have reached a condition similar to the pre-disturbance state, i.e. showing a great resilience and proving the high resprouting ability of local woody species. Such a fast recovery implies the presence of the necessary ecological interactions with local seed dispersers (da Silveira Bueno 2018). The role played by birds, and in particular by the Eurasian Jay (*Garrulus glandarius* L.), in the dispersal of *Quercus* acorns is well known (e.g.: Gomez 2003). Also, recent field surveys carried out in Sicily have confirmed the importance of such biotic interactions for the process of recovery of Mediterranean vegetation (La Mantia et al. 2015, La Mantia and da Silveira Bueno 2016, da Silveira Bueno 2018). However, the fire took place just once; recurrent wildfires may seriously hamper the regenerating capacity by native woody species, also causing soil erosion and degradation (Diaz-Delgado et al. 2002).

Comparing stone pine forest stands burned in 1982 (Plot 5 and Plot 6), the managed plot was composed by larger and higher individuals (mean DBH = 37 cm and Hm = 17 m), with a lower stand density (531 stems per hectare). The second tree layer was characterized by more developed and abundant holm oak individuals (> 90% in terms of frequency and almost 13% of the overall basal area). The managed plot showed a much higher basal area (66 m^2 ha^{-1} vs 37 m^2 ha^{-1}). In the unmanaged plot, pine individuals were smaller, determining a higher stand density (619 stems per hectare). Holm oak is well established in both plots due to its shade tolerance during seedling stage and the lack of competition after the fire destroyed the shrub cover. However, the higher light availability in the understory of the managed plot has favored its regeneration, as well as that of downy oak and *Ampelodesmos*. It is well recognized that an excessive pine cover may exert inhibitory effects for the growth and survival of thermophilous oaks in the understory of Mediterranean pine plantations (Manor et al. 2008, Pasta et al. 2012). Furthermore, such density values are far beyond the most recommended threshold for similar forest stands, that is 350-400 pines per hectare (Del Favero 2008). After fire passage, occasional regeneration by *Cupressus sempervirens* and *Pinus pinea* were also observed, but their saplings have died probably due to the excessive dominant tree cover, suggesting a very low regeneration performance by planted conifers. This was also due to the inability of stone pine to regenerate immediately after fire, as this species does not bear serotinous cones (Pausas et al. 2008). The regeneration of shrub species was not particularly represented in the managed plot, consisting the regeneration layer almost exclusively of *Ampelodesmos* (> 85% of total individuals). A massive regeneration by *Erica multiflora* is found in the unmanaged plot, where it probably benefited from the lack of understory management practices. The two plots share a similarly low plant species richness, despite a slight prevalence of forest species in the managed plot. Such low richness probably depended not only on a possible allelopathic effect by pines, but also on the lack of the necessary silvicultural treatments, namely thinning. The importance of thinning to enhance the overall biodiversity and to accelerate the renaturalization of Mediterranean plantations is largely acknowledged, for their strong influence on light availability, as well as on overstory-understory competitive interactions (e.g.: Gómez-Aparicio et al. 2009). Most of taxonomic groups appear to be negatively influenced by a too dense dominant canopy (Gil-Tena et al. 2007, Manor et al. 2008), so that exceeding some threshold value the interventions are absolutely required (Pasta et al. 2012). For instance, shade-intolerant plants and their associated biological communities may survive only in presence of a sufficient number of suitable-sized gaps (Heiri et al. 2009). Thinning after fire passage may also have a positive effect to favor the recovery of woody species, but keeping in mind that a too low tree density may significantly reduce the regeneration potential after a new fire event (García-Jiménez et al. 2017).

Comparison plots burned in 1954

The comparison between holm oak stands burned in 1954 (Plot 3 vs Plot 4), characterized by a longer post-fire dynamic, allowed us to appreciate the contrasting role of understory management on post-fire vegetation recovery, assessed in terms of forest structural development, establishment of natural regeneration, and species richness. In these plots, woody vegetation has had more time to develop and be diversified so that tree cover reached 80% and 70%, respectively. Differently from what observed in the holm oak stands burned in 1982, here the managed plot was more diversified both in terms of species composition and structure. This would prove that the management of Mediterranean afforestations subject to wildfires is a quite difficult task and no generalized approach can be established (Vallejo and Alloza 2012). In the managed plot, the contribution of holm oak was greatly reduced (from 87% to 28% in terms of basal area). Conversely, the contribution of other tree species, which attained large sizes (Mean DBH ranges from 21.7 cm of cork oak to 28 cm of downy oak), was significant. Accordingly, total basal area was far higher in the managed plot (almost 47 m^2 ha^{-1} vs 26 m^2 ha^{-1}). The regeneration of tree species was also much more abundant in the regularly managed plot (22'500 vs 6'500 individuals per hectare). As far as regeneration is concerned, in the managed plot there was a far higher number of *Q. ilex* coppice shoots (almost 6'000 per hectare). More similar was the understory condition, consisting of the same number of species with a similar development stage. However, the regeneration was more abundant in the unmanaged plot (5'800 vs 4'500 individuals per hectare), mostly due to the considerable presence of *Teucrium* spp.. The managed plot showed a higher species richness, especially due to the contribution of mantle species (order *Prunetalia spinosae*), as well as of Mediterranean perennial grasses (order *Hyparrhenietalia hirtae*). The same number of species of forest and pre-forest formations was found. The large gap in terms of species-richness between the two unmanaged plots dominated by holm oak probably depended on the different time since last wildfire. However, despite not directly measured, the fire intensity may have played a prominent role. The oldest cork oak individuals have probably survived the fire in 1954 thanks to the bark protection. Such passive strategy makes cork oak one of the most fire resistant Mediterranean oaks (Catry et al. 2010). Their limited diameter increase and the lack of natural regeneration are probably related to local sub-optimal edapho-climatic conditions as cork oak is known to be particularly demanding for such abiotic factors.

Comparison by dominant tree species

The comparison between the plots dominated by holm oak and stone pine (Plots 1-4 vs Plots 5-6), respectively, allowed us to assess the role played by the dominant tree species in the post-fire response. On average, holm oak canopy seemed to have a more positive effect on understory regeneration dynamics and richness than stone pine cover. The tree regeneration in the understory of holm oak forests was particularly favored in terms of abundance, but also a species-specific effect was found, being downy oak the species that benefited the most from holm oak as dominant species. The total regeneration of shrubs was not found to be strongly affected by dominant tree canopy. Conversely, species of forest and pre-forest communities tended to be more common in holm oak stands, while species linked to herbaceous communities tended to prefer stone pine stands. Importantly, species such as *Calicotome*, *Emerus*, *Spartium*, *Cistus salviifolius* and *Teucrium fruticans* were found to be exclusive of the understory of holm oak stands, indicating a crucial role for the conservation of biodiversity.

Comparison managed vs unmanaged

Also interesting was the comparison between managed and unmanaged plots, regardless of dominant tree species (Plots 1, 3 and 5 vs Plots 2, 4 and 6). Despite hosting a similar total number of plant species, these plots showed quite large differences in species identity. Species tied to forest communities were equally represented in both groups of plots. However, the other groups of species were found to be sensitive to forest management. Shrub species belonging to *Cisto-Ericetalia multiflorae* phytosociological order were negatively affected by understory management practices which, by contrast, seemed to favor the occurrence of mantle shrubs (Order *Prunetalia spinosae*) and species of Mediterranean perennial grasslands (Order *Hyparrhenietalia hirtae*).

All the investigated areas should be provided with a management plan including forest interventions aimed at favouring the gradual conversion from stone pine plantations to holm oak mixed forest stands. Such renaturalization process is widely occurring in the Mediterranean Basin (Pausas et al. 2004). For instance, a similar conversion has been observed within the afforestation carried out in 1928 at Casaboli wood (Palermo Mts.), where holm oak have reached a noteworthy size and definitely prevailed over pines, clearly revealing the potential vegetation (climax) (Troìa 1994, Maggiore et al. 2005).

Conclusions

One relevant factor constraining the success of Mediterranean plantations is the occurrence of wildfires, which may negatively affect seedling survival and establishment, seriously hindering the natural regeneration of planted species. Resilience to fire has a crucial importance in driving vegetation dynamics, as well as for the failure or success of forest plantations. Local forest stands appeared to be quite complex and diversified, so that the surveyed plots may represent different patches of a landscape mosaic resulting not only from differences in fire events and dominant tree species but also from post-fire silvicultural practices. Despite the few replicas of our field surveys do not allow making broad generalizations of the investigated natural processes, our research has confirmed the high resilience to wildfire of Mediterranean woody vegetation. In particular, we found that native *Quercus* spp. recovered very well after fire, confirming the possibility to use them for afforestation purposes without prior using *Pinus* spp. Also, species identity, autoecology, and provenance have to be carefully considered as the origin of plant material is recognized to significantly affect the establishment chance by plant species (González-Alonso et al. 2004).

We found that the understory management (understory cleaning and removal of dead biomass) had a role in the forest recovery after fire, influencing the structural and floristic characteristics of the forest stands, as well as the regeneration pattern of woody species. However, also the unmanaged plots were characterized by effective regeneration processes in the understory. This suggests that the option of no management after fire should be considered, in presence of sufficient propagules of native woody species.

A forest ecosystem subject to recurrent wildfires needs to be managed avoiding forest interventions which could hinder the natural dynamics, following the principles of systemic silviculture (e.g.: Ciancio and Nocentini 2011). The knowledge of post-fire vegetation response is crucial if we are to adopt management practices which take into account the ecological characteristics of the plant species, their ability to respond to and their resilience to fire. Future management interventions should be planned and addressed to favor the intrinsic ability of the ecosystem to develop, to mature and to recover after a disturbance event, without looking at any predefined structure and specific composition, following the natural dynamics and promoting the natural regeneration (Ciancio and Nocentini 2011).

The results of our field surveys, including long-term vegetation response, may be used in order to better manage Mediterranean afforested areas prone to frequent wildfires. Such Mediterranean forest ecosystems should be subjected to "*assisted natural regeneration, (re)introduction of tree or shrubby species, and fire-prevention measures*", following an integrated approach (Vallejo and Alloza 2012).

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