Volume IX ● Issue 2/2018 ● Pages 207–218

INTERDISCIPLINARIA ARCHAEOLOGICA
NATURAL SCIENCES IN ARCHAEOLOGY

homepage: http://www.iansa.eu

Thematic Review

The "Mediterranean Forest": A Perspective for Vegetation History Reconstruction

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A R T I C L E I N F O

Article history:
Received: 22nd September 2018
Accepted: 31st December 2018

Key words:
floristic studies
palynology
sclerophyllous
Quercus species
Meso-Mediterranean

A B S T R A C T

Starting from the multifaceted meaning of "Mediterranean", this thematic review wishes to reconnect the palaeobotanical with the phytogeographical approach in the reconstruction of the Mediterranean Forest of the past. The use of the term "Mediterranean" is somewhat ambiguous in its common use, and has not an unequivocal meaning in different research fields. In botany, geographical-floristic studies produce maps based on the distribution of the plant species; floristic-ecological studies, produce maps that deal with the distribution of the plant communities and their relationships with different habitats. This review reports on the different use of the term "Mediterranean" in geographical or floristic studies, and on the way climate and plant distributions are used to define the Mediterranean area. The Mediterranean Forest through the palynological records is then shortly reported on. Pollen analysis may be employed to reconstruct the Mediterranean Forest of the past but a number of problems make this a difficult task: low pollen preservation, lack of diagnostic features at low taxonomical level, and low pollen production of species which form the Mediterranean Forests. Variable images of this vegetation are visible in different landscapes, but the Mediterranean Forest often remains a sort of "ghost forest" in pollen spectra from the Mediterranean Region.

1. Introduction

"Mediterranean" and "Mediterranean Forest" are terms frequently used: either in a too generic manner or in a very specific sense. Their meanings differ not only when used by amateurs but also when they are mentioned in scientific papers, depending on the country, from the education and research fields of scholars. The "Mediterranean diet", for instance, is not only an eating pattern of the countries surrounding the Mediterranean sea, but also a way of naming the "good food" prepared in several restaurants of the world. Thus, to reply to what meant by the word *Mediterranean*, we can reply with Braudel (1985 in Blondel *et al.* 2010): "One thousand of things at a time". Even referring to the Mediterranean Sea, the adjective "Mediterranean" encompasses several different concepts: it may indicate geographical location (Mediterranean Basin, also pointing to the countries bordering the sea), climate (Mediterranean climate) or botanical features (Mediterranean flora and Mediterranean vegetation). This paper focuses on the use of the term "Mediterranean" and its interpretation in environmental/palaeoenvironmental studies with a focus on the botanical/palynological approach. It is known that the current landscape of plants is a result of different factors, making vegetation history an important chapter of the environmental sciences. The flora and vegetation are basically the results of climatic changes that have occurred over millions of years. Further variations have been recently added in as a function of the human interference that has drawn and re-drawn the plant landscape through the development of different cultures during the Holocene (Mercuri and Sadori, 2014; Sadori *et al.* 2013). This seems to have been particularly true for the Mediterranean Region, according to the opinion of Blondel *et al.* (2010): "Nowhere else more than in the Mediterranean Region has nature moulded people so much and have people in turn so deeply influenced landscapes". The reason for this deep interdependence between cultures and environment is actually visible in the nature of the plant communities around the Mediterranean Basin, a geographic area which shows

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a remarkable variety of topographical features, edaphic conditions, and plant communities.

With regard to vegetation history, the palaeo- and archaeo-botanical studies deal with the flora and vegetation changes as evidenced in long-term chronological records. Analyses of pollen and plant macroremains from sediment strata and archaeological layers provide lists of plants that better attends to the flora rather than the vegetation, but references to plant communities are highly informative for reconstructing landscapes. Single-case studies are often limited in time and in space, whereas syntheses of several sites allow for wide-ranging reconstructions that overcome specific local events (see, for example, Mercuri, 2014, for cultural landscapes reconstructed through pollen analyses). Local and regional studies can improve our knowledge on the cause-and-effect patterns which have determined broad palaeoenvironmental changes (sharp events or gradual transformations) under the various climate and anthropic influences. Synthesis of the data in a coherent scheme is needed for reconstruction of the vegetation history of each region, but the many inhomogeneities in the terminology concerning various vegetation types, often being referred to in a generic or ambiguous way, is a major difficulty in this task. In papers on palaeo- and archaeo-botany, the authors rarely explain to which plant community their results refer to, even if important exceptions exist (*e.g.* Colombaroli *et al.*, 2009, focusing on the dynamics and history of fires; Piovesan *et al.*, 2018, studying an application for the restoration of forest ecosystems). Certainly we can say that reaching an unequivocal, conclusive definition of the term "Mediterranean" is a hard task and is outside and not the aim of this paper. According to "Conservation International: Biodiversity Hotspots"[1], the Mediterranean Basin is one of the hotspots of plant biodiversity (22,500 species with 52% of endemic species against more then 6000 species in other parts of Europe). Due to this wealth of biodiversity, defining the limits of the Mediterranean biogeographical area is a topic that is deeply under discussion among bio-geographers. Therefore, our main purpose is to make the reader aware of the level of this difficulty and try to make less ambiguous the terminology referring to plant communities, and in particular the "Mediterranean Forest".

2. The geographical use of "Mediterranean" referring to plant communities

Recently, a catastrophic event made it quite clear that in layman's terms "Mediterranean Forest" is used to indicate a forest of the Mediterranean Region in a very generic way. On March 2015, a terrific storm scourged the coast of northern Tuscany. The fall of numerous trees changed the face of the Versilia coast. After this disaster, the local government officials decided to restore the "natural vegetation". In their view, the natural, Mediterranean vegetation of the area consisted of woods dominated by umbrella pine often mixed with holly oak. The media were speaking about the "wild Mediterranean Forest", meaning the woods that people are used to seeing in the territory. They believed those woods to be the natural vegetation of the area and in naming them used a geographical term (Mediterranean) derived from the proximity to the coast: But, are those woods the wild Mediterranean vegetation? Is merely growing near the Mediterranean Sea in itself sufficient to be some part of the "Mediterranean vegetation"? The reality is more a mosaic of several vegetation types that form parts of this so-called "wild forest", including pine plantations dominated by *Pinus pinea*[2] and *Pinus pinaster*, that have been planted as several reforestation events since Roman times, and were then intensified between the "600 and 800" ies (Giacomini, 1968; Mondino and Bernetti, 1998; Arrigoni, 1998), with an undergrowth of *Quercus ilex*, and a European vegetation consisting of deciduous trees such as *Quercus robur*, *Alnus glutinosa*, and *Carpinus betulus*.

The geographical use of the term "Mediterranean Forest" is also present in scientific papers belonging to research fields other than botany but concerning woodlands or bushlands of the countries facing the Mediterranean Sea (*e.g.* Cosandey *et al.*, 2005, on experimental studies on forest hydrology). In such papers, the term "Mediterranean Forest" and "macchia" are often reported as synonyms. Indeed, they are both vegetation types dominated by evergreen and sclerophyllous species, but they largely differ in their dominating habitus/growth forms: there is a prevalence of trees in the forest, and shrubs in the macchia (Arrigoni, 1996). The name "macchia" more properly refers to a very intricate, impenetrable plant community characterized by densely-branched, evergreen, sclerophyllous shrubs and climbing plants.

3. The use of the term "Mediterranean" in floristic studies

Narrowing to botany, the specific literature reveals great difficulty in finding an unambiguous definition/use of the adjective "Mediterranean". In general, two approaches can be used to describe the plant resources of a territory: the former is the geographical-floristic approach based on the local flora leading to the identification of phytochoria, *i.e.* areas with similar compositions of plant species (Takhtajan, 1986); the latter is the floristic-ecological approach based on the study of the distribution of plant communities and their relationships (Kent, 2012).

Numerous maps of Italy based on the geographical-floristic approach were published during the last century (Fiori, 1923; Arrigoni, 1980, Romagnoli, 2003). They are syntheses useful for the regionalization of areas on a geographical (*i.e.* large) scale. In this type of map (Figure 1),

[1] Mediterranean Basin September, 2011: http://www.biodiversityhotspots.org/xp/hotspots/mediterranean/Pages/default.aspx.

[2] Species names according to Euro+Med PlantBase (http://www.emplantbase.org/).

Figure 1. Geographical-floristic map of Italy (Arrigoni, 1980, Romagnoli, 2003).

the largest part of the Italian peninsula is included in the Euro-Siberian Region while only a narrow strip along the coastline, in addition to the whole of Sicily and Sardinia, is attributed to the Mediterranean Region.

The floristic-ecological approach focuses on the species that use the same local resources with different type of interactions, from independence to full interdependence (Kent, 2012). In Europe, phytosociological schools often employed this type of study (Géhu and Rivas-Martínez, 1981; Blasi, 2010; Biondi, 2011). It is particularly useful for studying plant communities on a local scale. The maps based on the floristic-ecological approach (Rivas-Martinez *et al.*, 2004, modified for Italy by Blasi and Biondi, 2017) also limited the Mediterranean Region to the coast of the Italian peninsula, and included the hills and mountains of Calabria, Puglia, Sardinia and Sicily. The integration of both the geographical-floristic and floristic-ecological maps constitutes a valuable tool for the study of the past flora and vegetation history at the local scale (see, for example, Mariotti Lippi *et al.*, 2015, for the reconstruction of the vegetation surrounding Grotta Paglicci-Apulia).

4. Climate and plant distribution to define the Mediterranean area

The Mediterranean climate is a typical, temperate, bi-seasonal climate with the dry period – summer – coincident with the season of highest temperatures, and with mild, wet winters (Koppen, 1936). Climate has been used to define the borders of the Mediterranean area. Gaussen (1954) used temperature as a single parameter; more specifically, he considered the average temperature of the coldest month of the year – January or February – as one of the most

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Table 1. Most important trees and shrubs and the main syntaxa related to the forests of the Mediterranean area, arranged according to the vegetation zonal belt. Vegetation belt and the distribution of species are according to Quézel and Médail (2003 modified); species names follow Euro+Med PlantBase (http://www.emplantbase.org/home.html). Syntaxa are according to Mucina *et al.* (2016).

Mediterranean vegetation belt	**Oro Mediterranean**	**Montane**	**Supra Mediterranean**	**Meso Mediterranean**	**Thermo Mediterranean**
Coldest month mean temperature	**– 7 / - 3 °C**	**-3 / 0°C**	**0 / 3°C**	**3 / 7°C**	**> 7°C**
Main syntaxa	Junipero-Pinetea sylvestris	Quercetalia pubescentis	Quercetalia pubescentis	Quercetalia ilicis	Pistacio-Rhamnetalia
		Geranio striati-Fagion Rhododendro pontici-Fagetalia orientalis	Querco-Cedretalia	Quercetalia calliprini	Pistacio-Pinetalia
		Querco-Cedretalia	Quercetalia calliprini	Pinetalia halepensis	
			Quercetalia ilicis		
Main trees and shrubs	*Abies (A. alba, A. pinsapo, A. maroccana, A. numidica)*	*Abies (A. alba subsp. apenninica, A. pinsapo, A. maroccana, A. nebrodensis, A. cephalonica, A. borisii-regi, A. numidica, A. cilicica, A. bornumulleriana, A. nordmanniana)*			
		Cedrus (C. atlantica, C. libani, C. deodara)	*Cedrus (C. atlantica, C. libani)*		
	Pinus (P. sylvestris, P. nigra complex)	*Pinus (P. heldreichii, P. nigra complex)*		*Pinus (P. halepensis, P. brutia)*	
	Juniperus (J. excelsa, J. phoenicea, J. foetidissima, J. hemisphaerica, J. drupacea, J. thurifera)				*Junipers (Juniperus deltoides, J. drupacea, J. oxycedrus, J. thurifera)*
				Cupressus sempervirens	*Cupressus atlantica*
		deciduous *Quercus (Q. brandtii, Q. petraea)*	deciduous *Quercus (Q. petraea)*		
			marcescent *Quercus (Q. pyrenaica, Q. pubescens, Q. cerris, Q. frainetto, Q. faginea, Q. infectoria, Q. libani)*	marcescent *Quercus (Q. pyrenaica, Q. pubescens, Q. ithaburensis)*	marcescent *Quercus (Q. ithaburensis, Q. pubescens)*
		evergreen *Quercus (Q. brandtii, Q. petraea, Q. ilex, Q. rotundifolia)*	evergreen *Quercus (Q. rotundifolia. Q. faginea, Q. ilex)*	evergreen *Quercus (Q. rotundifolia. Q. faginea, Q. ilex, Q. coccifera, Q. alnifolia, Q. suber)*	evergreen *Quercus (Q. lusitanica, Q. calliprini)*
	Berberis (B. aetnensis, B. cretica)				
	Prunus prostrata				
	Cytisus (C. oromediterraneaus, C. balansae, C. spinescens, C. aolicus, etc.)				
			Ostrya carpinifolia		
			Carpinus (C. betulus, C. orientalis)		
				Arbutus (A. unedo, A. andrachne)	
				Erica spp.	
				Acer sempervirens	
				Fraxinus ornus	
				Pistacia atlantica	*Pistacia (P. lentiscus, P. atlantica)*
					Olea europaea
					Myrtus communis
					Phillyrea (P. latifolia, P. angustifolia)
					Euphorbia dendroides
					Rhamnus (R. alaternus, R. oleoides, R. lycioides)
					Ceratonia siliqua
					Cneorum tricoccum
					Teucrium fruticans
					Globularia alypum
					Tetraclinis articularis

relevant parameters, establishing a mean value >5°C as the limit for the Mediterranean area. This value allows a line to be drawn that includes the Mediterranean coastal areas of Europe, West Asia and North-West Africa, and excludes part of North-East Africa. In a similar vein, Desfontaines (in De Montgolfier, 2002) took into consideration only one factor, precipitation, and paid attention to the length of the dry season and distribution of rainfall over the year. Considering the occurrence of 1–3 months of aridity as a benchmark, he moved the limits of the Mediterranean area to Spain, North Africa and the Middle East. Northern Italy, which was out of the Mediterranean area in Gaussen's map, has hence been partially included.

Taking into consideration the distribution of plant communities as an indicator of bioclimatic areas, the dominance of evergreen, sclerophyllous species was historically used for defining the Mediterranean area. With this perspective (Table 1), the Meso-Mediterranean Forest displays the physiognomy of a forest dominated by *Quercus* species, especially *Q. ilex* and *Q. rotundifolia*. Remarkably, these oak trees do not tolerate extreme temperatures and drought conditions and are therefore substituted by sclerophyllous, tall shrubs in a few areas of southern Italy and in large areas of northern Africa. Such plant communities are Thermo-Mediterranean communities, characterized by a few species of small evergreen trees with non-dense foliage ("*arboscellus*" according to Arrigoni, 1996) such as *Olea europaea* and *Ceratonia siliqua*, *Acacia* species and shrubs that generally give rise to open formations, or forest with pines (such as *P. halepensis*) .

In the Mediterranean Region (1–5 of Figure 1) the forests dominated by *Quercus ilex* are diffusely spread from the coastal areas to the mountain. *Q. ilex* can also occur in forests of the Eurosiberian Region (6–8 of Figure 1) dominated by deciduous and/or marcescent trees, like *Q. pubescens* and sometimes *Q. cerris* and *Q. frainetto* (marcescent according to Quézel and Médail, 2003; Garcia-Mijangos *et al.*, 2015, *i.e.* plants that maintain dried leaves for most part of the winter and are able to have photosynthetic activity for 1–2 months longer than true deciduous trees, at least for parts of the leaves).

Within this general scheme, topography, soil features, temperatures and rainfall have interacted with each other forming a variety of habitats that defy any resolution of continuity. In addition, human interference has also affected flora assemblages, shaping and re-shaping landscapes during

Table 2. Number of genera and species of the most important families of the Mediterranean woody flora. Number of genera and species are according to Kubitzki's Families and Genera of Vascular plants (1990–2011). Data for the Mediterranean area are from Euro+MedPlantBase. Alien species, species growing out of the Mediterranean area and exclusive of the Atlantic islands (Canary Islands, Madeira and Azores) are excluded. 1: Page, 1992a; 2: Page, 1992 b; 3: Kubitzki, 1993; 4: Rohwer, 1993a; 5: Rohwer, 1993b; 6: Hüber, 1998; 7: Kubitzki and Rudall, 1998; 8: Conran, 1998; 9: Mayo *et al.*, 1998; 10: Dransfield and Uhl, 1998; 11: Stevens *et al.*, 2004; 12: Medan and Schirarend, 2004; 13: Green, 2004; 14: Köhler, 2007; 15: Wen, 2007; 16: Pell *et al.*, 2011; 17: Wilson, 2011; 18: Kubitzki *et al.*, 2011. a: The PlantList.org.

	Family	Total n. genera	Total n. Species	Euro+med genera		Euro+med species	Distribution of the family	Pollination agent
1	Cupressaceae	20	125	3		11	Worldwide	Wind
2	Pinaceae	12	200	3		25	Worldwide	Wind
3	Fagaceae	8	620/750	3		40	Temperate, Subtropics (Worldwide)	Wind
4	Moraceae	37	1100	1	*Ficus*	4	Tropics, Subtropics, Warm Temperate	Insects (Wind ?)
5	Lauraceae	50	2500/3500	1	*Laurus*	1	Tropics, Subtropics, Temperate	Insects (Wind ?)
6	Dioscoreaceae	20	600	1	*Dioscorea*	6	Tropics, Subtropics, Warm Temperate	Insects
7	Asparagaceae	1	170/300	1	*Asparagus*	33	Tropics, Subtropics, Mediterranean	Insects/Zoo
8	Smilacaceae	3	320	1	*Smilax*	2	Tropics, Subtropics, Mediterranean	Insects/Zoo (Wind ?)
9	Araceae	104	3300	7		57	Tropics (Worldwide)	Insects (Wind ?)
10	Palmae	190	2000	4		6	Tropics, Subtropics, Mediterranean	Insects/Zoo
11	Ericaecae	124	4100	4		22	Worldwide Temperate, Tropics montane	Insects/Wind
12	Rhamnaceae	52	925	5		47	Tropics, Subtropics, Warm Temperate	Insects (Wind ?)
13	Oleaceae	25	600	9		17	Tropics, Subtropics (Temperate)	Insects/Wind
14	Buxaceae	5	100	1	*Buxus*	2	Tropics, Subtropics, Mediterranean (Wordlwide)	Insects/Zoo(Wind)
15	Vitaceae	14	750	3		3	Tropics, Subtropics, Temperate	Insects/Wind
16	Anacardiaceae	81	800	4		17	Tropics, Subtropics, Warm Temperate	Insects (Wind)
17	Myrtaceae	142	5500	3		4	Tropics, Subtropics, Mediterranean	Insects/Zoo (Wind ?)
18	Rutaceae	154	2100	3		40	Tropics, Subtropics, Mediterranean	Insects/Zoo
a	Apocynaceae	402	5031	20		68	Tropics, Subtropics, Warm Temperate	Insects/Zoo
a	Araliaceae	46	1505	1	*Hedera*	12	Tropics, Subtropics, Warm Temperate	Insects (Wind ?)

the development of different cultures over the millennia. According to Naveh and Dan (1973), the Mediterranean plant landscape was made by "several variants of different states of degradation and regeneration of the original forest" that gave origin to the distribution in time and space of a mosaic of vegetation formations.

5. The "Mediterranean Forest" through palynological records

Reconstruction of long-term flora and vegetation changes is a field of research that has been especially developed by palynology (*e.g.* de Beaulieu *et al.* 2005; Jalut *et al.* 2009; Roberts et al. 2011; Magri *et al.* 2015), even in interdisciplinary cooperations between the human and natural sciences (Sadori *et al.* 2015; Mariotti Lippi *et al.* 2015; Mercuri et al. 2015; Mercuri and Florenzano in press). Despite the fundamental role of palynology in vegetation history, there are limits to delineating the pollen profile of the Mediterranean Forest. The main problems are low pollen preservation, lack of features diagnostic at low taxonomical levels, and the low pollen production of many species that form the Mediterranean Forest.

Regarding preservation, for example, it is generally accepted that the pollen wall may be damaged by an alkaline pH causing the deterioration of exine sporopollenins. As the "Mediterranean Forest" dominated by *Q. ilex* is known to prefer calcareous soils, which are characterized by high pH values, it is likely that in such Mediterranean forest soils pollen has low preservation.

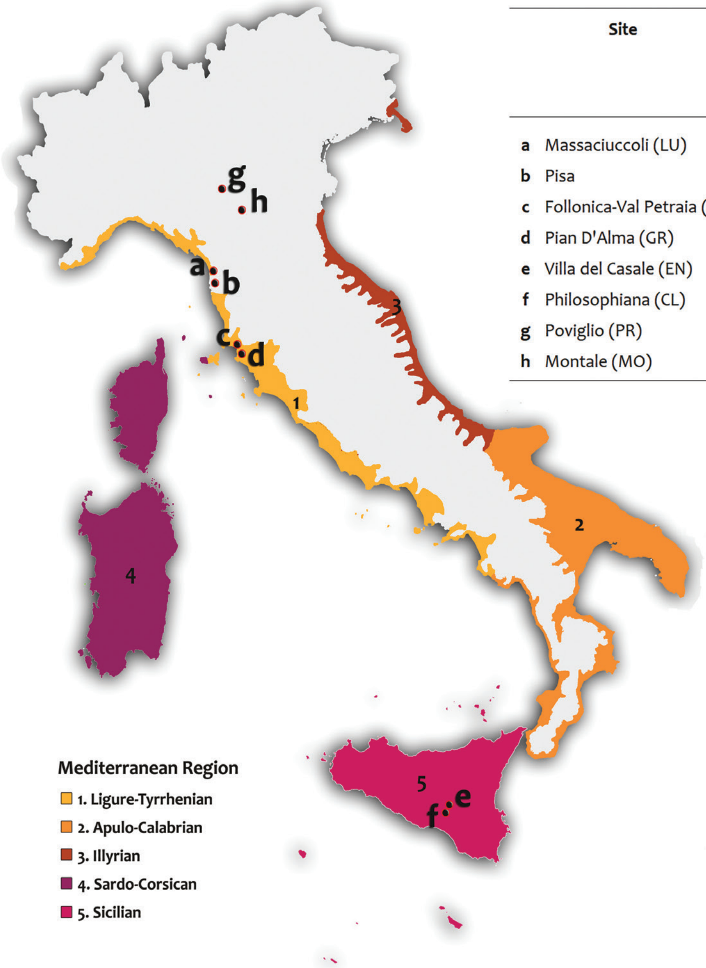
Regarding identification, pollen morphology does not always allow discrimination to the species, genus, or even family level. Taking *Juniperus* as an example, its pollen is commonly attributed to the *Juniperus* type, a group of pollen grains that includes also *Cupressus* (Moore *et al.*, 1981). Cupressaceae pollen is known for the fragility of its wall (Spieksma *et al.*, 1994) and for its peculiar behaviour during hydration, which provokes the breakage of the thin exine layer as a consequence of the swelling of the intine (Danti *et al.*, 2011). The low resolution of its pollen morphology may cause its identification to stop at the family level, making pollen data from this important family useless for floristic and phytogeographical studies. Other gymnosperms, like *Pinus*, are also hardly identified at species level in ancient sediments.

Regarding pollen production, many plant species of the Mediterranean Forest (Table 2) are pollinated by animals, insects in particular, and are weak pollen producers (Blondel and Aronson, 1995). This feature may be related to the tropical origin of many species, as indicated by the current distribution of families that belong to, for example, Asparagaceae, Dioscoreaceae, Moraceae, and Rhamnaceae. The production of small amounts of pollen makes these zoophilous plants underrepresented and infrequently recorded in pollen spectra (Carrión 2002a; Mercuri *et al.*, 2010). Exceptions have been reported which may reveal a very local presence of flowers/plants, such as in the case of *Arbutus unedo* (a shrub which is up to subdominant in *Q. ilex* wood and dominant in "tall macchia" in Drescher-Schneider *et al.*, 2007). In the case of *Pistacia*, contrasting records from high (55% in Tinner *et al.*, 2009) to low values (3% in Florenzano *et al.*, 2013) suggest that these plants may have a rather variable image in the pollen spectra from southern Italy.

With its nature of anemophilous tree, *Quercus ilex* is generally the best represented plant of the Mediterranean Forest in pollen spectra from sites located inside (*e.g.* Gruger and Thulin, 1998) or near (*e.g.* Colombaroli *et al.*, 2007; Magri and Sadori, 1999; Sadori and Narcisi, 2001) to the border of the Mediterranean Region (Figure 2). Studies on the current diffusion of *Q. ilex* pollen in Tuscany (Mariotti Lippi *et al.*, 2000) has given evidence that, at the same site, *Q. ilex* has similar values of pollen percentages in the spectra as it has dominance in the plant community[3]. As *Quercus ilex* is not exclusive to the Meso-Mediterranean Forest and also grows in the Supra-Mediterranean Forest (according to EUNIS classification: G2.122 Supra-Mediterranean Quercus ilex Forests; 9340 Directive Habitat: Lauvel *et al.*, 2013), we must take into account that its pollen can belong to plants growing in both the Meso-Mediterranean Forest and the Supra-Mediterranean Forest communities. To identify the Mediterranean Forest from a palynological point of view, it is thus necessary to look for pollen grains produced by other species of this plant community. The deciduous and marcescent species of *Quercus*, growing in association with *Q. ilex* (Table 1), do not give good hints because their pollen is rarely identifiable to species level. Despite the low amount of pollen produced, suitable plants for identifying the Mediterranean Forest are *Arbutus*, *Pistacia* and *Fraxinus ornus* (the latter is also in SubMediterranean forests, and its well-preserved pollen grains are discernible from those of other ash species: Moore *et al.*, 1991). *Myrtus*, *Phillyrea* and *Rhamnus* may be added to the list of plants suitable for identifying the Mediterranean Forest, more properly belonging to the Thermo-Mediterranean community. Pollen from climbers, as *Smilax*, or herbaceous plants, such as *Asparagus*, may also support an attribution to the Mediterranean Forest. The *Asparagus* inclusion may be controversial: in fact, *Asparagus acutifolius* grows in the *Quercus ilex* forest (*Quercion ilicis* or *Fraxino-Quercion ilicis*) and in the SubMediterranean forest (*Quercetalia pubescentis*), and *A. officinalis* is grown in a variety of habitats and is not typical of the Mediterranean Forests. However, the presence of this rare pollen, which unfortunately cannot be easily identified at species level, may be taken into consideration to support the attribution of certain pollen spectra to a Mediterranean Forest.

Indeed, *Ostrya carpinifolia* and *Carpinus orientalis* (often combined in one single pollen type), together with *C. betulus*, are suitable for identifying the Supra-Mediterranean Forest (Tables 1 and 2).

[3] Dominance is the cover value of the species in the community.



	Site	Pollen percentages of plants of the Mediterranean Forest mean (%)	max (%)	References
a	Massaciuccoli (LU)	2.7	23.5	Menozzi et al., 2002; Mariotti Lippi et al., 2007a
b	Pisa	2.9	5.3	Mariotti Lippi et al., 2007b
c	Follonica-Val Petraia (LI)	≤ 0.5	-	Mariotti Lippi et al., 2000
d	Pian D'Alma (GR)	4.6	5.7	Mariotti Lippi et al., 2002
e	Villa del Casale (EN)	0.4	2.2	Montecchi and Mercuri, 2018
f	Philosophiana (CL)	1.9	6.8	Mercuri et al., 2017
g	Poviglio (PR)	0.03%	-	Cremaschi et al., 2016
h	Montale (MO)	0.03%	-	Mercuri et al., 2006

Figure 2. Pollen percentages of the plants growing in the Mediterranean Forest (Quercus ilex, Arbutus, Pistacia, Myrtus, Rhamnus, Asparagus) inside or close to the Mediterranean Ecoregion as indicated by pollen analyses of selected sites. Data from Poviglio and Montale (located in northern Italy) are added to include comparison with the Euro-Siberian Region.

As reported above, the Mediterranean Forest is a plant community dominated by evergreen sclerophyllous (high and low) trees and shrubs. These communities largely consist of *Quercus ilex* in the central part of the Mediterranean Basin, *Q. rotundifolia* to the western side, *Q. coccifera* subsp. *coccifera* in both, and *Q. coccifera* subsp. *calliprinos* to the eastern side.

Based on pollen morphology, the discrimination of oaks is quite problematic: the *Q. ilex* type includes the greater part of the evergreen oaks, though not *Q. suber*, and is discriminated by the semideciduous and deciduous oak types (Smit, 1973). They are high pollen-producers because they are anemophilous plants, as well as the gymnosperms such as *Pinus* and Cupressaceae. Pollen from these plants largely overwhelms those of the other components of the same plant community. They often seem to be prevalent in the woody flora of the Mediterranean, but this is a mere effect of their masking effect over the entomophilous species which actually prevail in the Mediterranean contexts. All these conditions make the Mediterranean Forest poorly identifiable in the pollen spectra from the Mediterranean Region.

6. Postglacial history of the Mediterranean Forest

An enormous set of biological archives are available to provide data on the changes in the flora and vegetation of the Mediterranean regions. These changes have occurred not only in the history of the far past but also in recent times, together determining the shape of the present-day Mediterranean landscape (Sadori *et al.*, 2013).

Moving on to the tracks of the Mediterranean Forest as seen through the pollen spectra, we must take into account the oscillations of the pollen sum of all the species living in the Mediterranean Forest. As reported above, the pollen does not allow the discrimination of plants growing in the Meso-Mediterranean, Supra-Mediterranean or Thermo-Mediterranean communities. However, the occurrence of pollen belonging to elements typical of the Meso-Mediterranean community (Table 1) seems to have been more frequent in the pollen spectra, and confirms the occurrence (but not its extension) of this plant formation in the past.

In the western part of the Mediterranean Basin, at the beginning of the postglacial period, the Mediterranean elements are low and discontinuous in pollen records (Carrión, 2002b; Gil-Romera *et al.*, 2009). Indeed, in the early part of the Holocene, the vegetation cover was dominated by deciduous broadleaved trees (Jalut *et al.*, 2009). In Spain, Mediterranean communities spread in the mid-Holocene, in concomitance with the increasing aridity, with maximum values at around 5900 cal. BP[4]. *Pistacia* is well represented, as are the evergreen *Quercus*, *Phillyrea* and *Rhamnus*. A similar scenario also resulted from the study of a core from Sète, in France, where *Pistacia*, mainly *P. terebinthus*, was already present in the 6th millennium BP and continued to spread until the end of the 5th millennium (Court-Picon *et al.*, 2010). Thus, the diffusion of the Mediterranean Forest in the western part of the Mediterranean Basin may be placed to the beginning of the mid-Holocene, a phase correlated with lake-level lowering in the Jura (eastern France) and glacier retreat in the Alps (Magny *et al.*, 2002; Jalut *et al.*, 2009).

In the central part of the Mediterranean Basin, the Mediterranean Forest is clearly visible in Holocene spectra of the central and southern Italian regions (*e.g.* Magri and Sadori, 1999; Sadori and Narcisi, 2001; Sadori *et al.*, 2013). In Sicily, *Q. ilex* pollen is well recorded along the Holocene stratigraphy, showing greater values in the upper part of the sequence. *Fraxinus ornus* and *Pistacia* were intermittently present at the beginning of the Holocene, but their amount increased upwards with peak of *Pistacia* pollen occurring in samples dated around 7200 BP, when other Mediterranean elements were also abundant (Sadori and Narcisi, 2001). In northern Italy, the occurrence of the Mediterranean Forest is sporadically recorded along the Tyrrhenian coasts, because of the occurrence of coastal wetlands (Bellini *et al.*, 2009) and the presence of an extensive alluvial plain in north-eastern Italy. Where it was found, *Q. ilex* pollen shows increasing values from around the 6th millennium (6000–5000 cal BP), sporadically accompanied by *Pistacia* (Arobba *et al.*, 2004; Colombaroli *et al.*, 2007; Montanari *et al.*, 2015). In Dalmatia, evergreen vegetation, mainly *Juniperus* and *Phillyrea*, replaced the deciduous oak forests in the 8th millennium (about 7600 BP), while evergreen oaks spread one millennium later (about 6100 BP; Sadori *et al.*, 2011).

In the western part of the Mediterranean Basin, at Delfinos in Crete, Greece, *Quercus coccifera*-type pollen is recorded from about 8400 BP and presents an increasing trend up to about 6000 BP. *Pistacia* is discontinuous and peaks in coincidence with *Fraxinus ornus* or *Phillyrea* (Bottema and Sarpaki, 2003). Forests with *Q. calliprinos* as the dominant tree in association with *Pistacia palaestina* were widespread in the Mediterranean area of Israel from 6000 BP to 400 BP (Liphschitz and Biger, 1990). A mild early Holocene in the eastern part of the Mediterranean Basin is supported by the record of *Pistacia* pollen in terrestrial sites and marine cores (Rossignol-Strick, 1999).

Altogether, pollen records suggest that the Mediterranean Forest was already developed in the eastern part of the Mediterranean Basin at the beginning of the Holocene, and then spread to the western and central parts of the Mediterranean Basin in coincidence with the decline of the deciduous broadleaved forest during the mid-Holocene.

7. Mediterranean Forest and human activities

The mid-Holocene was not only a period of climate changes and the diffusion of the Mediterranean Forest in the central and western Mediterranean basin, but it also represents a crucial period in human history. The socio-cultural changes are the starting point towards new human-environment relationships, deeply affecting the territory surrounding human settlements. Therefore, it is not always easy to distinguish the changes that have been induced by climate, by human practices, or by both these causes as they coupled and overlapped (Roberts *et al.*, 2011; Sadori *et al.*, 2011; Marignani *et al.*, 2017), with an increasing importance of the human impact with time, as is also happening currently (Barbero *et al.*, 1990). In general, the spread of agrarian systems, including field cultivation and pastures, caused a dramatic decrease in woodlands, especially visible in continental and Mediterranean Italy since the Bronze Age (*e.g.*, in Lago di Mezzano: Mercuri and Sadori, 2012; Sadori, 2018). Moreover, the pastoral economy has been largely responsible for the limitation of forests and the spreading of shrubby Mediterranean vegetation formations in southern Italy (*e.g.*, Florenzano, 2019).

Slash and burn are among the most ancient activities documented in human history. Past fire activity has been recorded all over the world during the whole Holocene. Studies of the history of fire indicate that changes in fire regimes are directly related to climatic changes (Mouillot and Field, 2005; Vannière *et al.*, 2011). Either way, a direct connection between the incidence of fire and the presence of human populations appears during the middle to the late Holocene (Vannière *et al.*, 2011), just in coincidence with the development of the Mediterranean cultures. Fires in forested areas may have been voluntarily set to attain open areas for pastures. Traces of ancient fire activity are also recorded in areas where palaeonvironmental reconstruction indicates the occurrence of Meso-Mediterranean communities (Vannière *et al.*, 2011).

Besides fire, cutting was a common practice for implementing crop cultivation. By way of example, fire seems to have prevented the spread of *Q. ilex* during the mid-Holocene in northern Tuscany, in Italy (Colombaroli *et al.*, 2007); a decline in deciduous and evergreen oaks has been recorded in Crete, Greece, in coincidence with an increasing amount of *Olea* pollen at about 5700 BP, suggesting the planting of olive groves from the foothills towards the sea (Bottema and Sarpaki, 2003). Indeed, olive groves deeply impacted the Mediterranean landscape, often replacing pre-existing forests (Moriondo *et al.*, 2013), and despite the variable pollen production of the trees, the rise of the *Olea* pollen curve in pollen spectra signals the development of cultural landscapes and the arboriculture of the last three

[4] The chronologies of the paragraph are according to the original papers.

Figure 3. Meso-Mediterranean Forest dominated by *Quercus ilex* at Populonia, Leghorn, Italy.

millennia in many Mediterranean countries (Mercuri *et al.*, 2013; Florenzano *et al.*, 2017).

With respects to the exploitation of natural resources, wood-cutting and coppicing have impacted the forests around the Mediterranean Basin for millennia. Among the main trees of the Meso-Mediterranean Forest, evergreen oaks have been used as a source of timber. *Q. ilex* did not seem to have been selected by humans, as it happened to *Q. suber* (Toumi and Lumaret, 1998). *Q. ilex* wood was largely used as fuel or employed for the construction of elements of ship structures (*e.g.* Giachi *et al.*, 2003). According to Reille (1992), human action may also be responsible for the establishment of *Q. ilex*, as indicated through pollen analysis in Corsica (France) during the Subatlantic, where its diffusion seems to have been a consequence of the deforestation that mainly affected *Pinus* and *Erica arborea*.

Even if the typical elements of the Meso-Mediterranean forest have been exploited by humans, few of them have been subjected to cultivation, for example, *Q. suber* and *Q. coccifera*; the former was cultivated for cork production, the latter for the production of the kermes dye, obtained from the insect *Kermes vermilio* Planchon, 1864, Hemiptera. Cultivation possibly also favoured the diffusion of these oaks beyond their original geographic areas.

8. Concluding remarks

In literature, the term "Mediterranean Forest" is often used to indicate the three different plant communities: Thermo-, Meso- and Supra-Mediterranean communities. The Thermo-Mediterranean community generally does not display the true physiognomy of a forest. Despite the fact it includes the emblem Mediterranean species *Olea europaea*, this is not the most appropriate plant association for a Mediterranean Forest. Moreover, the cultivation of *Olea* for a long time has also favoured the spread of this plant beyond their natural geographic areas. Other plant communities, *i.e.* the Pine forests, have to be considered a variety of the "Mediterranean Forest", but they are hardly identified in pollen analyses. According to these facts, in the palaeoenvironmental reconstruction, the "Mediterranean forest" *sensu stricto* can be considered the forest dominated by evergreen, sclerophyllous *Quercus* species (Figure 3). This is probably the best Mediterranean Forest detectable by pollen analysis, but unfortunately often remains a sort of "ghost forest" in pollen spectra from the Mediterranean Region.

Acknowledgments

The authors wish to thank the referees for the suggestions useful for improving the text.

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