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An overview of the Holocene vegetation history from the central Mediterranean coasts

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ABSTRACT - A review of twenty-six pollen records from coastal areas of central Mediterranean countries (including Malta, Sardinia, Corsica, Italian Peninsula, Sicily, Croatia, and Greece) is presented, in order to describe the general processes characterizing the environmental evolution of this region and to detect the main causes producing landscape change during the last thousands of years. An overview of the main vegetation types shows a rather diverse composition and structure of the vegetational landscape, mostly depending on geomorphic situations, climate conditions, biological processes and human history. This variability makes it impossible to define a pollen stratigraphical scheme valid for the entire area during the last thousands of years. A general and progressive anthropization trend of the vegetational landscape is observed since the Neolithic, evolving with different times and modes from site to site. In many cases human populations adapted their activities to the locally existing natural resources, for example by exploiting native plant taxa (e.g., *Olea*, *Vitis*, and *Quercus suber*) or transforming natural coastal wetlands in saltworks, always determining deep landscape changes and depletion of the native biodiversity. The responses of vegetation to geomorphic processes and climate have generally been different from site to site: in some cases only one sector of the central Mediterranean Basin was involved (e.g. Tyrrhenian expansion of *Alnus* around 5200 cal. BP), while in other cases extensive geographical processes occurred (e.g. development of coastal wetlands around 7000 cal. BP).

This long-term environmental perspective indicates that the current coastal ecosystems of the central Mediterranean Basin represent an ephemeral snap-shot, destined to new, abrupt and dramatic future changes. Thus, palaeoenvironmental studies may prove of fundamental importance in estimating both the environmental instability typical of each geographical context and the degree of vulnerability of coastal ecosystems, so providing suggestions for appropriate conservation actions in coastal environments.

Key words: Holocene, pollen, coastal vegetation, human impact

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INTRODUCTION

Coasts are unstable environments under the constant impact and influence of geomorphological processes and climate changes, which have always modified both the physiognomy of the vegetation and the land availability for coastal ecosystems.

In addition, coastal areas provide outstanding examples of long-lasting processes of natural ecosystems depletion related to human activity. In fact, since the rise of agriculturally based societies and the associated population expansion, humans have produced cumulative and often irreversible impacts on natural coastal landscapes and coastal biotic resources worldwide (Kirch, 2005). This admixture of different factors of environmental change, together with the scenario of a future ever-increasing impact on coasts, mainly due to demographic (Bijlsma et al., 1996) and climatic factors (McLean et al., 2001), with the related sea level rise (Nicholls, 2004), represents a major threat for the conservation of the ephemeral surviving natural ecosystems and for their biodiversity. In such context, the scientific reports agree that the Mediterranean coasts are particularly at risk (e.g. Nicholls et al., 1999). They are very densely populated, with a long history of exploitation of environmental resources and transformation of coastal landscape, documented since the Neolithic times. In addition, wide regions of the Mediterranean are currently interested by a general trend

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towards desertification, involving also the coastal domain, with a still unclear origin and development (Millennium Ecosystem Assessment, 2005; Sciortino et al., 2000; Kéfi et al., 2007).

This overall worrying picture has stimulated a lively debate on the adequacy of the scientific programs supporting the urgent governmental actions to be undertaken for a more responsible management of coastal areas. In their analysis of the status of the European coastal areas management, Elliott et al. (1999) suggest that spatial and temporal monitoring require to be performed at appropriate scales to provide long-term and large-area assessment of environmental quality. However, in the current situation, the monitoring scales are often inappropriate e.g., assessments done at a small scale are extrapolated to wider scales, and experimental designs generally adopted provide only a snapshot assessment of the environment. According to Elliott et al. (1999) "There is insufficient attention to carrying out detailed long-term studies that may develop new ideas and concepts relevant to estuarine and coastal management". An important contribution to get round this difficulty may be provided by the development of a pollen database of coastal sites allowing a millennial-scale monitoring of the coastal ecosystems evolution.

The main goal of this work is to make a review of the pollen data available in the literature from the central Mediterranean in order to describe the general processes characterizing the environmental evolution of this region and to detect the main causes producing landscape change during the last thousands of years. Special attention will be paid to assess, with a millennial perspective, whether, where, when and how the main current factors affecting the coastal ecosystems have acted in the past to produce vegetation changes in the central Mediterranean coastal area.

COASTAL POLLEN RECORDS IN THE CENTRAL MEDITERRANEAN REGION

The pollen dataset of the central Mediterranean coastal region is currently represented by twenty-six main sites, included in a solid chronological framework. They are located in Sardinia, Corsica, Italian Peninsula, Sicily, Malta, Croatia and W Greece (Fig. 1). Unfortunately, there are wide parts of the central Mediterranean territory with no pollen records or with scattered unpublished data. This is the case of the central and northern Adriatic Italian coasts and of East Sardinia, the latter being a region particularly affected by desertification processes, whose coastal environmental evolution deserves special attention. In the following paragraphs, the most representative sites will be shortly presented in order to develop interpretations on the history of the coastal environments of the central Mediterranean region (Fig. 2). The chronological scale is expressed in calibrated years BP. When age-models were not provided in the original papers, we applied an age-depth model based on linear interpolation between calibrated dates in order to make the chronological setting of the coastal database uniform.

Mistras Lagoon

Mistras (site 1 in Fig. 1) is a hypersaline lagoon of about 50 cm water depth covering a surface of 600 hectares, located along the northwestern part of the Oristano Gulf, south of the Sinis Peninsula (West coast of Sardinia, Italy), close to the ancient city of Tharros, one of the most important Phoenician and Roman archaeological sites in Sardinia.

The chronology of the core is provided by seven AMS radiocarbon dates carried out on bulk sediment samples and shells, suggesting for the pollen record the age 5300-1600 cal. BP (Di Rita and Melis, submitted). Between 5300 and 4600 cal. BP, the landscape was characterized by rather open vegetation, with a *Pistacia*-dominated scrubland mostly located along the coast, and a holm oak-dominated woodland inland (Fig. 2). Saline conditions were also evidenced in an early Neolithic

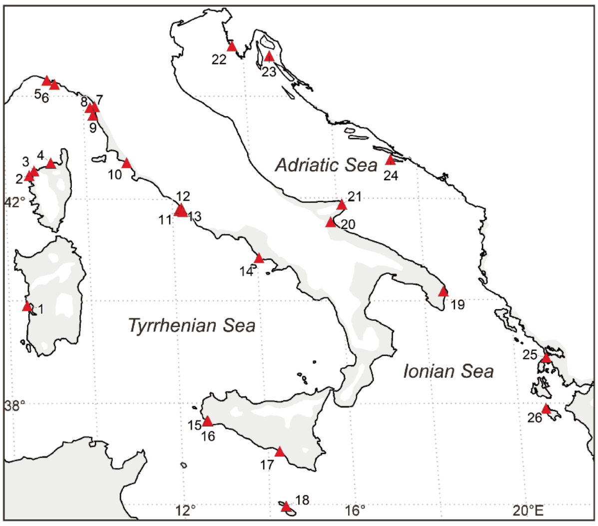

Fig. 1 - Location of the coastal pollen sites mentioned in the text: 1. Mistras (Di Rita and Melis, submitted); 2. Crovani (Reille, 1992); 3. Le Fango (Reille, 1992); 4. Saleccia (Reille, 1992); 5. Rapallo (Bellini et al., 2009); 6. Sestri Levante (Bellini et al., 2009); 7. Lago di Massaciuccoli (cores LML and LMM) (Colombaroli et al., 2007; Marchetto et al., 2008); 8. Lago di Massaciuccoli (core MSC) (Mariotti Lippi et al., 2007; Bellini et al., 2009); 9. Arno (core M1) (Aguzzi et al., 2007); 10. Ombrone Plain (Biserni and van Geel, 2005); 11. Pesce Luna (Milli et al., in press); 12. Stagno di Maccarese (core LOI) (Di Rita et al., 2010); 13. Stagno di Ostia (Bellotti et al., 2011); 14. Lago d'Averno (Grüger and Thulin, 1999); 15. Lago Preola (Calò et al., 2012); 16. Gorgo Basso (Tinner et al., 2009); 17. Biviere di Gela (Noti et al., 2009); 18. Malta (Burmarrad: Djamali et al., 2012; Salina Bay: Carroll et al., 2012; 19. Lago Alimini Piccolo (Di Rita and Magri, 2009); 20. Lago Salso (Di Rita et al., 2011; Di Rita, 2012); 21. Lago Battaglia (Caroli and Caldara 2007); 22. Lake Palu (Beug, 1977); 23. Lake Vrana (Schmidt et al., 2000); 24. Malo Jezero (Jahns and van den Bogaard, 1998); 25. Lake Voulkaria (Jahns, 2005); 26. Alikes Lagoon (Avramidis et al., 2012). The grey area represents the modern distribution of evergreen vegetation.

settlement in the Oristano Gulf (Pittau et al., 2012). A wide salt-marsh occupied the lagoonal margin. Between 4600 and 3950 cal. BP, complex dynamics involved both the arboreal and herbaceous vegetation: an expansion of evergreen vegetation was accompanied by a decrease of salt-marsh vegetation probably due to local hydrological processes. Rather stable vegetation conditions marked the period between 3950 and 2050 cal. BP, corresponding to the phase of maximum human frequentation of the area, characterized by the development of the Nuragic civilisation and the building of the Punic-Roman city of Tharros, documented in the pollen diagram by continuous records of anthropogenic indicators. Between 2050 and 1600 cal. BP, a new expansion of evergreen vegetation and a less intensive land use are recorded. A marked increase in *Quercus suber* type suggests silvicultural practices aimed at exploiting cork during the Roman Times.

Crovani

Six kilometers north of the Le Fango mouth, the Crovani pond (site 2 in Fig. 1) presents physiognomical characters similar to Le Fango (Reille, 1992). However, the structure and composition of the vegetation of the two sites are slightly different (Fig. 2). The pollen sequence of Crovani, provided with two radiocarbon dates, spans approximately the last 5100 cal. years. The vegetation history of the Crovani pond is characterized by open forest conditions up to 4900 cal. BP, with *Erica arborea* and evergreen oaks dominant. In this period, there is also a significant abundance of *Alnus*, testifying a well-developed riparian vegetation. At ca. 4400 cal. BP, an important opening of the landscape is recorded, mainly involving evergreen vegetation replaced by grasses and sedges. When vegetation recovers, after a few centuries, there is a new increase in evergreen elements, mostly represented by *Erica arborea* and oaks, coupled with a reduction of the *Alnus* wood.

After ca. 2000 cal. BP a new spread of alder is recorded. The landscape is characterized by a semi-open vegetation, dominated by evergreen oaks and *Erica arborea*. The upper part of the sequence shows a final abrupt opening of the vegetation, notably related to a drop of *Erica* and a steady decrease of evergreen oaks.

Le Fango

Le Fango (site 3 in Fig. 1) is a closed wooded site at the mouth of a tributary of the river that flows down the Cinto Massif (2710 m), the highest mountain of Corsica (Reille, 1992). Four radiocarbon dates provide a chronological framework dating back approximately to the last 7500 years. On the whole, the vegetation history of the site is characterized by forested conditions (Fig. 2). The lower part of the sequence up to 6500 cal. BP, testifies for a wooded landscape dominated by *Erica arborea* and *Pinus laricio*, accompanied by appreciable percentages of deciduous oaks. After this phase, the arboreal vegetation experienced a remarkable increase in evergreen oaks. At around 5500 cal. BP a sudden opening of the landscape is recorded, marked by an important expansion of Cyperaceae, coupled with the development of riparian trees, especially *Salix* and *Alnus*. A remarkable spread of *Alnus* forest is recorded from ca. 5100 to 1400 cal. BP. The vegetation history of the upper part of the sequence shows a considerable reduction of the alder forest, a spread of pine forests, of both *Pinus laricio* and *Pinus pinaster* + *P. halepensis*. The end of the sequence records a new opening of the landscape, dominated by plants communities of *Cistus* and *Erica arborea*.

Saleccia

Saleccia (site 4 in Fig. 1) is a lagoon formed behind gravel bars, located at the northern side of Corsica (Reille, 1992). The pollen record dates back approximately to the last 7200 years, according to an age-depth model based on five radiocarbon dates. The vegetation history of the site is characterized by forest conditions up to ca. 2700 cal. BP, with *Erica arborea* as the main floristic element, accompanied by different partners through time (Fig. 2). In particular, between ca. 7200 and 6500 cal. BP *Erica arborea* dominated the forested landscape together with deciduous oaks, then a decrease in oaks allowed the development of evergreen vegetation, characterized by *Olea*, *Phillyrea*, *Pistacia, Arbutus* and *Quercus ilex* type. At ca. 2000 cal. BP, an appreciable opening of the vegetation is recorded, mostly due to a drop of *Erica*. The vegetation history of the last millennium shows a new, rapid and important recovery of *Erica* vegetation. However, a complete disappearance of many evergreen taxa contributed to keeping the landscape open. The end of the sequence outlines a rather open landscape due to a remarkable drop of *Erica*, matching an expansion of *Pinus*, probably related to plantations, and a new spread of evergreen vegetation.

Sestri Levante and Rapallo

The vegetation history of Sestri Levante (site 6 in Fig. 1) is revealed by two cores collected near the Gromolo stream (Bellini et al., 2009) from sandy silt and peat levels dated between ca. 8000 and 6000 cal. BP, and referable to swampy retro-dunal environments.

In this time interval, the Sestri Levante Plain and nearby relieves were characterized by a landscape with a mosaic vegetation. Mediterranean maquis was established on the dry environments, mostly characterized by sandy soils, while mesophilous woods rich in firs characterized the damper environments, presumably restricted to the foothills of the Apennines. This patchy landscape was related to the presence of swampy depressions created by a system of sandbars within the coastal plain, as well as to the confluence of two main streams.

The pollen record from Rapallo (site 5 in Fig. 1) spans the interval between c. 8000 and 5500 cal. BP (Bellini et al., 2009). Along the whole sequence a major signal of

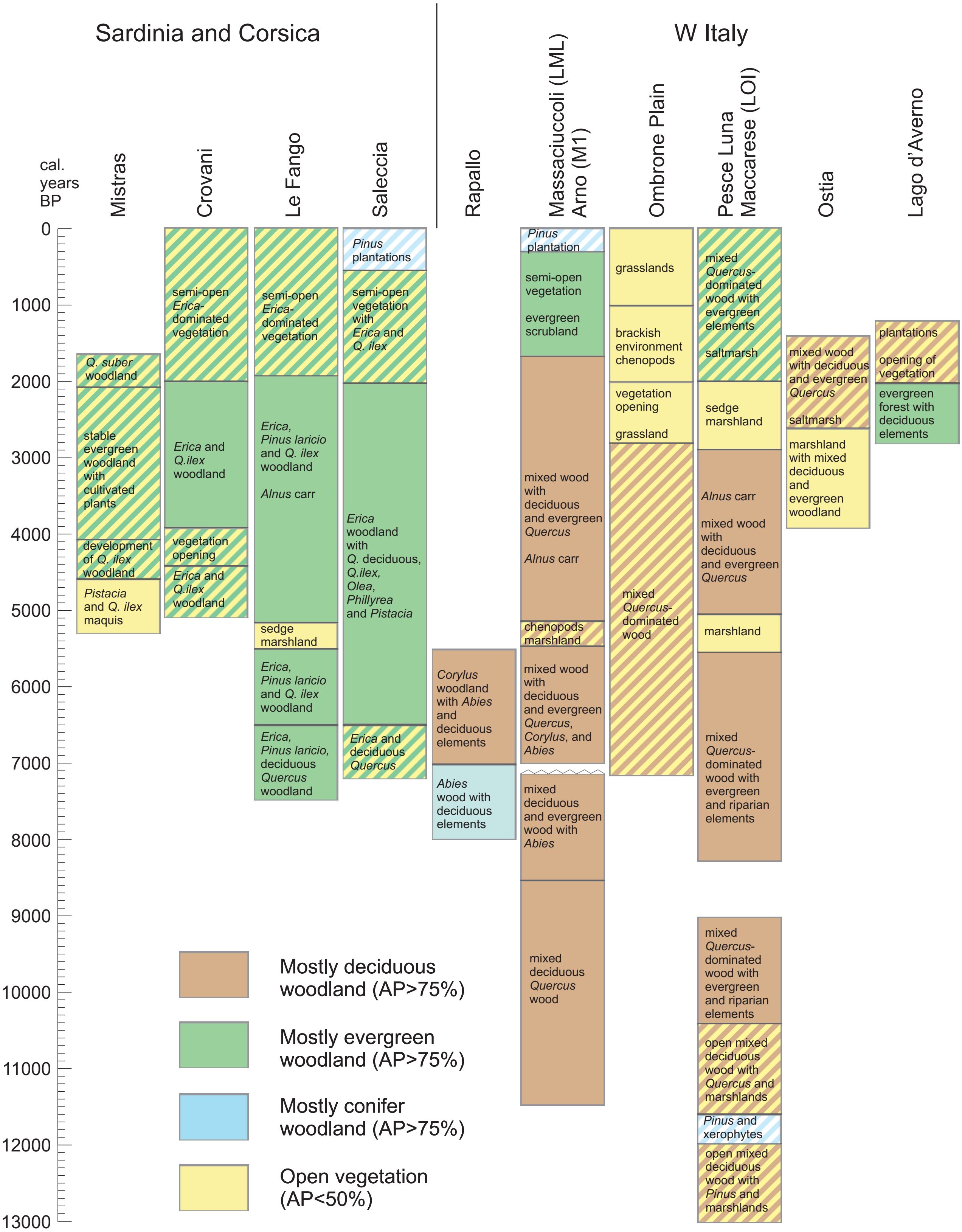

Fig. 2 - Simplified scheme of the main vegetation types recorded in the coastal pollen sites of the central Mediterranean region.

hazel is evident. *Abies*-dominated woods with *Ulmus*, *Tilia*, and deciduous *Quercus* were particularly developed only between 8000 and 7000 cal. BP; afterwards, the presence of *Abies* in the landscape decreased significantly. Around 5500 cal. BP, an expansion of open meso-thermophilous woods with oak, hazel and alder is recorded (Fig. 2).

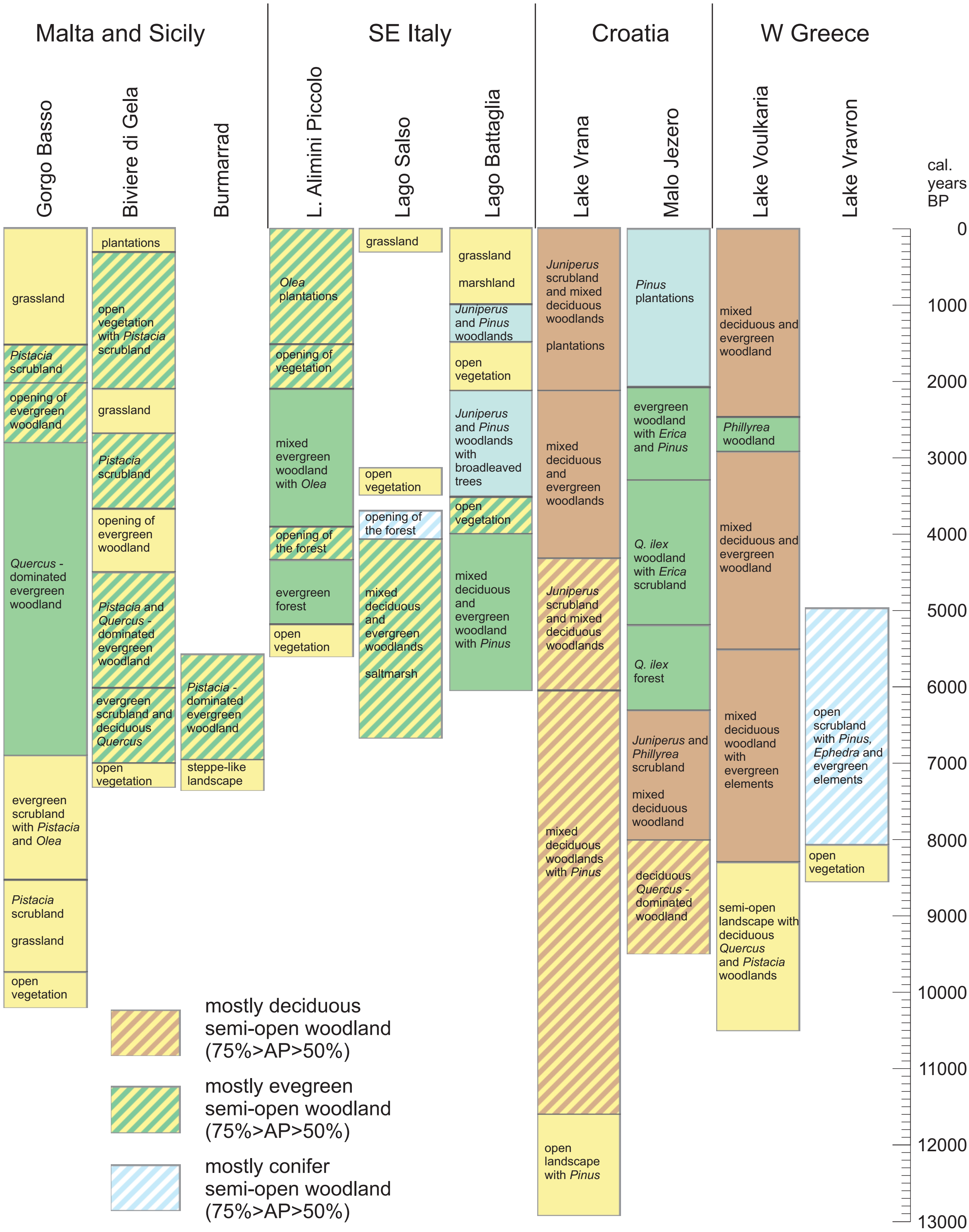

Fig. 2 - ... Continued

Massaciuccoli

Massaciuccoli is a coastal lake located in the Versilia Plain, in northern Tuscany. The lake originated as a retrodunal basin after the last sea transgression (Versilian Transgression) (Aguzzi et al., 2007). The sediments of the marshy area were collected in the context of two international projects and analysed by different teams of palaeoecologists (sites 7 and 8 in Fig. 1).

Core MSC

The uppermost 34 m of the core revealed the Holocene vegetation history (Menozzi et al., 2002; Mariotti Lippi et al., 2007). The pollen sequence spans approximately the time period between 10,000 cal. BP and the Roman times as indicated by 18 radiocarbon dates.

At the beginning of the Holocene this area was mainly covered by deciduous woodlands, in which *Quercus*, *Corylus* and *Alnus* were the dominant taxa. *Abies* spread around 9800 cal. BP and rapidly became the most important vegetational element of the landscape. Between 9400 and 7900 cal. BP the pollen record is interrupted due to the deposition of a thick sandy layer, containing very low numbers of pollen grains. This event was considered the result of a marine transgression occurred between 10,400 and 6600 cal. BP (Antonioli et al., 2000). Between 6600 and 5900 cal. BP, the vegetation was composed of coniferous and broadleaved woodlands, with *Abies*, *Corylus*, and deciduous oaks as main trees. An important development of riparian vegetation, mostly represented by a remarkable increase in *Alnus*, occurred especially from ca. 5600 to 4200 cal. BP. Between 4200 and 2700 cal. BP an expansion of *Vitis* is recorded together with a significant frequency of riparian trees, such as *Alnus* and *Salix*. This spread of *Vitis* is interpreted as a result of an early agricultural practice of management of wild grapevines, growing in riparian communities with alders and willows (Mariotti Lippi et al., 2007). The uppermost part of the sequence represents the Roman period, characterized by a semi-open landscape with deciduous oaks and *Erica*. An expansion of Cyperaceae and aquatics is recorded at the end of the sequence, preceded by a possible brackish event stressed by a peak of Chenopodiaceae.

Cores LML and LMM

The two cores are characterized, on the whole, by eight dates (one date was rejected) dating back to the last 7000 years (Colombaroli et al., 2007; Marchetto et al., 2008). The vegetation history mainly reflects the shift from natural or quasi-natural ecosystems to the modern human-dominated landscape (Fig. 2). At the base of the record a mixed evergreen and deciduous forests of *Quercus*, *Pinus* and *Abies alba* probably marks the re-establishment of the vegetation cover after a significant marine transgression (Antonioli et al., 2000). After 6000 cal. BP a drastic decline of *Abies alba* occurred in the area. According to Colombaroli et al. (2007) this process, matching high values in micro-charcoal concentration, would be attributable to increased fire activity. Around 5400 cal. BP the vegetation surrounding the site was mostly dominated by halophilic communities of Chenopodiaceae, pointing to the expansion of salty marshlands. This event has been related to a shift towards a drier climate (Marchetto et al., 2008). After this phase, the vegetation of the area was characterized by a significant development of *Alnus*, while the landscape experienced a new important spread of dense woods of mixed evergreen and deciduous oaks. Only at the end of the Roman period, around 1500 cal. BP, a distinct opening of the landscape is recorded, probably related to strong human impact. The development of shrubby vegetation dominated by *Phillyrea* and *Erica*, paralleling a coeval steady decrease in evergreen oaks, was accompanied by an increase in regional fire frequency. On the basis of the pollen signal (e.g. cultivation of *Secale* and other cereals) Colombaroli et al. (2007) assume that most of the fires were the result of clearance events aimed at opening up new areas for agriculture. The vegetational degradation increased during the past 700 years and was strongly related to intensification of agricultural practices. The sequence ends with a remarkable expansion of *Pinus* due to the widespread plantations of the last few centuries.

Arno Delta

The vegetation history of the Arno Delta area was reconstructed by means of pollen analyses on a 105-m-long core, drilled near the present shoreline, ca. 5 km south of the river mouth (Aguzzi et al., 2007). The Holocene part of the sequence is included in the first 55 metres of the sediment core, whose chronology, spanning from ca. 3450 to 11500 cal. BP, is provided by four radiocarbon dates.

Between 11500 and 8500 cal. BP the pollen record suggests a landscape dominated by a dense mixed deciduous oak wood (Fig. 2). Between 8500 and 3450 cal. BP the diagram suggests a mosaic of vegetation types characterized by mixed woods with *Pinus*, deciduous oaks, and mediterranean and mountain taxa.

Ombrone Plain

The core was collected three kilometers from the coastline, in the alluvial plain of the Ombrone River (site 10 in Fig. 1), near the town of Grosseto in southern Tuscany (Biserni and van Geel, 2005). The pollen sequence, provided with four radiocarbon dates, outlines the vegetation history of the area during the last 7200 years (Fig. 2). The diagram records a scarcely forested landscape dominated by oaks and other deciduous trees up to ca. 2800 cal. BP, when a process towards an opening of the landscape started, probably related to increasing human activity, as indicated by the cereal record. At the same time, local environmental conditions changed from a brackish-marine environment to temporary freshwater conditions. In the upper part of the sequence, a marked expansion of salt-marsh indicators took place, pointing to the establishment of brackish conditions due to a renewed marine influence, probably in response to both a climate process and local saltworks establishment. The pollen record ends with a decrease in Chenopodiaceae and a coeval important increase in Poaceae and Asteraceae, pointing to the formation of grasslands.

Pesce Luna and Stagno di Maccarese

The pollen sequence from Pesce Luna (site 11 in Fig.

1), approximately 5 km north the Tiber River mouth, provided a record spanning approximately from 13,000 to 9000 cal. BP (Milli et al., in press). The record reflects both the vegetation changes determined by the abrupt climate fluctuations of the late glacial period-onset of the Holocene, and by local environmental shifts, related to hydrological changes (Fig. 2).

Between 13,000 and 12,200 cal. BP the landscape surrounding the Tiber delta area was characterized by a mixed deciduous woodland, accompanied by an appreciable presence of evergreen elements. Around 12,000 cal. BP the arboreal vegetation underwent a clear reduction in broadleaved trees, a significant development of *Pinus*, and an appreciable increase in xerophytes. This vegetational change reflects the climate conditions of the Younger Dryas interval.

At the onset of the Holocene (ca. 11,600 cal. BP), a forest recovery, mostly involving oaks and *Corylus*, was recorded in the whole region, but at Pesce Luna it was partly overshadowed by a marked increase in grasses and sedges suggesting local development of widespread and unstable marshy environments. More stable conditions took place around 10,400 cal. BP and persisted until the end of the record (ca. 9000 cal. BP), favouring the development of a dense deciduous planitial forest, rich in evergreen and riparian elements typical of the local coastal and estuarine environments, respectively.

During the Holocene, the coastal area near the mouth of the Tiber river was shaped by intense geomorphic processes, producing two coastal basins, currently reclaimed: Stagno di Maccarese (site 12 in Fig. 1), located north of the Tiber mouth and Stagno di Ostia (site 13 in Fig. 1), south of the Tiber mouth. Palaeobotanical analyses were carried out on lacustrine sediments excavated during an archaeological survey in the area of the Fiumicino International Airport, formerly occupied by Stagno di Maccarese (core LOI: Di Rita et al., 2010; 2012). An age-depth model based on five radiocarbon dates indicates that the sedimentary sequence spans approximately the last 8300 years (Fig. 2).

Between approximately 8300 and 5400 cal. BP the Maccarese area was covered by dense oak-dominated forests, probably with a patchy distribution of evergreen and deciduous communities. The herbaceous vegetation was mostly composed of sedges and grasses, probably representing local elements of marshy environments. An abrupt change around 5400 cal. BP marked the transition to an open landscape, dominated first by Poaceae, followed by Cyperaceae and then by other herbaceous taxa. At the same time there is evidence of human activity documented by a peak in the micro-charcoal concentration record indicating local fire, matching an appreciable amount of cereal-type pollen, and consistent with the archaeological surfaces of the nearby middle Eneolithic settlement of Le Cerquete-Fianello, dated between 5200 and 4950 cal. BP (Di Rita et al., 2010; 2012a).

Between 5100 and 2900 cal. BP there is a remarkable expansion of riparian trees, mostly represented by *Alnus*, with *Salix*, and *Fraxinus*. This change may be related to increased fluvial inflow in the basin and/or the formation of a broad alder carr bordering the lake.

Between 2900 and 1800 cal. BP a new development of marshlands is indicated by a succession of different herbaceous taxa (Poaceae, Cyperaceae/Juncaceae, and other herbs). A slight increase in Chenopodiaceae around 2600 cal. BP, testified also by carpological analyses (*Chenopodium glaucum*), and indicating increased salinity, is contemporary to the usage of the basin as saltworks by the local Etruscan populations in the 6th century BC (Morelli et al., 2004; Giraudi, 2004). On the whole, very weak evidence of human activity is found between the Eneolithic and Etruscan period in the pollen diagram, as the instability of this coastal area may have severely limited the extent and continuity of human occupations.

After 1800 cal. BP, when the Romans exploited the area, a new expansion of arboreal vegetation is recorded. The landscape was characterized by evergreen and deciduous oak-dominated forests, with the evergreen component probably mostly located seawards. An increase in *Juniperus* and *Pinus*, coupled with increases of evergreen shrubs, (Ericaceae, *Pistacia* and *Phillyrea*), outline the establishment of the modern coastal vegetation in the Tiber delta area. Anthropogenic markers, including cereals, Cannabaceae and *Juglans* environment, are continuously found since the Roman exploitation of the area (1st century AD).

Stagno di Ostia

Stagno di Ostia (site 13 in Fig. 1), south of the Tiber delta is currently a dried out lake, as a result of land reclamation in the last two centuries. The analyzed core was collected in the vicinity of the archaeological site of Ostia Antica. Two AMS datings indicate an age between 1900 BC and 600 AD (Bellotti et al., 2011; Di Rita et al., 2012a).

Between 1900 and 600 BC Stagno di Ostia was a freshwater wetland characterized by lush reeds dominated by Cyperaceae. The coastal landscape around the Tiber delta was dominated by mixed oak forests rich in evergreen elements (Fig. 2).

Around 600 BC the lake basin was affected by a sudden entry of seawater, as suggested by a peak of foraminiferal linings, turning the freshwater body into a brackish pond, quickly colonized by vegetation typical of salty wetlands (Chenopodiaceae and *Ruppia*). This change coincides chronologically with the foundation of Ostia Antica, as reported by Livy. However, at that time the beach-barrier separating the Ostia marsh from the sea was still too narrow and unsafe against storms and/or river mouth migrations for permanent human occupation; so Ostia could be only a strategic outpost controlling salt extraction. Only from 450 BC onwards, a significant amount of cultivated and anthropochore plants indicates an intensive exploitation of the area by human communities, coinciding with the first archaeological evidence retrieved from the archaeological site of Ostia Antica. High frequencies of chenopods suggest the existence of major local saltworks, which had a considerable development around the Tiber delta region in Imperial times (1st century AD). In the same period the two major ports of Claudius and Trajan were built, determining marked environmental changes in the Tiber delta area (Sadori et al., 2010).

Lago d'Averno

Lago d'Averno (site 14 in Fig. 1) is a volcanic lake in the Phlegrean Fields, west of Naples. The lake formed some time after the Avernus eruption, i.e. less than 3800 radiocarbon years ago (Rosi and Sbrana, 1987). The pollen analysis refers to core AV14K2, collected in the lacustrine sediments, which were not radiocarbon dated. However, a strong correlation of the environmental changes provided by the record with well-dated historical events and with the bradyseismic history of the region allowed ascribing the whole sequence approximately to the period 800 BC - 800 AD (Grüger and Thulin, 1998).

The record is pervaded by clear evidence of human impact. However, the intensity of human pressure on the vegetation changed with time. The lower part of the record points to a mixed oak vegetation, dominated by deciduous oaks and other deciduous elements (Fig. 2). An abrupt vegetational change records the transition to the next phase, outlining a landscape covered by evergreen woods, mainly composed by oaks with a significant presence of *Olea*, *Phillyrea* and *Pistacia*. This phase, related to the Greek colonization, does not seem particularly affected by human influence, presumably because the "Avernus" was considered to be a holy place.

In the year 37 BC the physiognomy of the lake changed abruptly as a consequence of the building of a Roman harbour (*Portus Julius*). A canal was opened to connect the sea with the lake. The salinity of the lake, indicated by the diatoms record, shows a dramatic increase. The evergreen vegetation of the lake was felled to construct a shipyard and other military buildings. A general opening of the landscape with the development of herbaceous vegetation, mostly represented by Poaceae, Brassicaceae and synanthropic weeds like *Mercurialis*, records also a new increase in deciduous oaks and the significant presence of conifers (*Pinus* and *Juniperus* type) and other anthropogenic trees (*Juglans*, *Castanea* and *Platanus*) (Grüger and Thulin, 1998).

The last phase of the sequence outlines a declining human impact, probably in coincidence of the collapse of the Roman Empire. The landscape was characterized by increasing forest conditions with well represented deciduous vegetation, mostly oaks, hornbeams and hazels. Also the evergreen vegetation experienced a significant increase of shrubs, mainly *Pistacia* and *Myrtus*.

Gorgo Basso and Lago Preola

Gorgo Basso (site 16 in Fig. 1) is a small lake of karstic origin with no important inlet or outlet located in south-western Sicily, ca. 2.2 km from the sea. The chronology of the core is based on ten AMS radiocarbon dates, carried out on terrestrial plant macrofossils, providing an age spanning from 10,200 cal. BP to the present time (Tinner et al., 2009). Between 10,200 and 9750 cal. BP the landscape was characterized by herbaceous communities, testifying for reed environments. Trees and shrubs were only sparsely distributed and probably restricted to favourable microhabitats. Between 9750 and 8500 cal. BP there was a major development of *Pistacia*-dominated scrublands. *Olea* communities expanded only after ca. 8500 cal. BP. The low values of AP between 8500 and 6900 cal. BP suggest that the landscape was still open. An increase of anthropogenic indicators and a decline of *Olea* and *Pistacia* at ca. 7300 cal. BP suggest human impact on the natural evergreen ecosystems. Around 6900 cal. BP a marked change corresponds to the establishment of a dense evergreen *Olea europaea*-*Quercus ilex* forest, which characterized the landscape until around 2800 cal. BP, although with phases of evergreen cover reduction, the most important one occurring between 4500 and 3700 cal. BP. After 2800 cal. BP a progressive disruption of Mediterranean forest and scrubland occurred, probably associated with the intensification of agricultural activity, as revealed by the marked expansion of crops and weeds. The pollen record documents the definitive collapse of evergreen *O. europaea*-*Q. ilex* forests, replaced between 2100 and 1500 cal. BP by almost pure *Pistacia* scrublands. Finally, around 1500 cal. BP the *Pistacia* scrublands were replaced by open environments and crop plantations. A pronounced expansion of *Eucalyptus* pollen, recorded since AD 1883, reflects its local introduction during the 19th and 20th centuries, mainly for drainage activity (Tinner et al., 2009).

Lago Preola (site 15 in Fig. 1) is a medium-sized lake of ca. 33 ha, located approx. 2 km from Gorgo Basso (Calò et al., 2012). Its chronology is based on 4 calibrated AMS radiocarbon dates of terrestrial plant material and bulk sediments from core LPBC, and correlation with nearby dated sediment cores. The pollen sequence spans from ca. 10,300 cal. BP to the present (Tinner et al., 2009).

Between 10,300 and 9600 cal. BP the landscape was characterized by herb-dominated communities. After 9600 cal. BP, a major increase in *Pistacia* suggests the development of scrublands near the lake. However, from ca. 9400 cal. BP the *Pistacia* maquis progressively declined reaching a minimum between 8000 and 7000 cal. BP. At the same time, a woodland with *Quercus* evergreen and *Olea* expanded. Between 7000 and 2000 cal. BP the woodland communities of evergreen oaks and *Olea* dominated the landscape, together with a *Pistacia* scrubland that reached its maximum expansion between 2000 and 1500 cal. BP. After 1500 cal. BP a clear collapse of arboreal vegetation is recorded. The expansion of herbs included taxa favored by human activity (e.g. Cerealia type, Chenopodiaceae and *Rumex*). Increases in *Pinus* and *Eucalyptus* are consistent with the plantations established during the last century (Calò et al., 2012).

Biviere di Gela

Biviere di Gela (site 17 in Fig. 1) is a lake located in SE Sicily coast. The chronological framework is provided by 6 AMS radiocarbon dates, dating the pollen sequence approximately to the last 7300 years (Noti et al., 2009).

The area surrounding Biviere di Gela became forested only at ca. 7200 cal. BP, with *Juniperus* and deciduous trees communities, mainly composed of *Quercus*, *Ostrya* and *Fraxinus*. After 6600 cal. BP this type of vegetation was almost completely replaced by evergreen vegetation, dominated by *Q. ilex*, *Olea* and *Pistacia* scrublands. Evergreen forests and scrublands dominated the landscape until ca. 5000 cal. BP, then declined in response to human impact, which was probably exacerbated by a general trend towards dry climate. In particular, a major reduction of the evergreen vegetation cover was recorded between 4500 and 3700 cal. BP. After a recovery of evergreen forest between 3700 and 2600 cal. BP, the diagram documents the final forest disruption, possibly related to the onset of the historically documented Greek colonization. Despite an expansion of *Pistacia*-dominated scrubland, between 1500 and 1000 cal. BP, the landscape kept open until the present day (Noti et al., 2009).

Malta

The site of Burmarrad (site 18 in Fig. 1) is a floodplain located in the north-western sector of Malta Island (Djamali et al., 2012). Pollen analysis was carried out on the 14 m long core BM1. The chronology of the pollen record spanning from 7350 to 5600 cal. BP is based on five radiocarbon dates measured from charcoals and peat sediment samples.

The vegetation between 7350 and 6950 cal. BP was characterized by an almost tree-less steppe-like open landscape dominated by Poaceae, Asteraceae and *Plantago* (Fig. 2). The depositional basin was a freshwater peat bog with aquatic and hygrophilous taxa. At ca. 6950 cal. BP the steppe-like vegetation was suddenly replaced by a dense *Pistacia* scrubland, with a low but continuous presence of evergreen *Quercus* and *Erica*.

Traces of human activities are evident in the pollen diagram since the beginning of the record, but became more pronounced after the onset of the Temple Cultural Phase at ca. 6050 cal. BP determining a gradual and conspicuous decline of the evergreen vegetation cover that paralleled an increase in anthropogenic pollen types indicating overgrazing and soil erosion.

From ca. 7000 cal. BP a continued input of sea water in the littoral wetlands, related to the mid-Holocene marine transgression, contributed in establishing a true marine environment, characterized by the development of chenopod communities and significant increases in dinoflagellates and microforaminifera. These depositional conditions persisted up to the top of the pollen record (Djamali et al., 2012).

The other pollen sites analysed in Malta generally depict a quite different environmental evolution (Carroll et al., 2012). Deforestation from *Pinus*-Cupressaceae woodland in the early Neolithic is followed by a long, but relatively stable, history of agriculturally degraded environments up to the present day. In particular, between 6800 and 4300 cal. BP the pollen record of Salina Bay, offshore from the Burmarrad site, shows high frequencies of cereal pollen, *Plantago* and Poaceae, accompanied by *Asphodelus* and *Urtica*, suggesting an open landscape shaped by arable agriculture, where grazing was also an important part of the agricultural economy. This mixed farming agriculture continued until around 4300 cal. BP, when cereal pollen declined and *Plantago* rised, possibly as a consequence of less intensive arable agriculture and increased pastoralism.

According to Carroll et al. (2012), the collapse of this cereal-based agriculture appears strongly linked to a regional aridification occurred around 4300 cal. BP.

Lago Alimini Piccolo

Lago Alimini Piccolo (site 19 in Fig. 1) is the largest natural freshwater lake in Apulia, mainly fed by springs located in the southwestern side of the lake. It is linked, by means of a narrow canal, to a brackish lake (Lago Alimini Grande), in turn connected to the Adriatic Sea. The chronological framework of the pollen record is based on five AMS radiocarbon dates indicating an age spanning approximately the last 5600 cal. BP (Di Rita and Magri, 2009). The period between 5600 and 5200 cal. BP was characterized by high amounts of Chenopodiaceae and Cichorioideae, likely resulting from selective preservation of pollen grains (Fig. 2). Between 5200 and 4350 cal. BP, the landscape was covered by dense oak-dominated Mediterranean evergreen vegetation, with *Pistacia*, *Olea*, *Phillyrea* and Ericaceae. Between 4350 and 3900 cal. BP, the Alimini area experienced a distinct opening of the forest, particularly affecting evergreen oaks. This event is characterized by a clear decrease in AP percentages and concentrations, a rapid change in vegetation composition and a contemporary increase in the number of taxa. Most herbaceous taxa show percentage increases, but the complete absence of both cereal pollen and other reliable anthropogenic indicators suggests that this forest reduction was not influenced by human activity. Between 3900 and 2100 cal. BP, the vegetation history of the Alimini area outlines a new forest expansion characterized by a remarkable increase in evergreen shrubs, including Mediterranean oaks. However, the forest cover shows a steady and moderate depletion through time, associated with a development of herbs and shrubs. This process might be due to a progressive increase of human activities during the Bronze Age, but also to a natural transition possibly induced by even slight precipitation or temperature changes. From 2600 to 2100 cal. BP, the area experienced a phase of increased human activity due to the documented Messapian, Greek and Roman occupations of the Salento Peninsula, witnessed by an almost continuous presence of cereals and a clear evidence of forest depletion. Between ca. 2100 and 1500 cal. BP, during the Roman occupation and up to the end of the Roman Empire, a significant opening of the oak-dominated forest with the expansion of several herbaceous taxa, especially Chenopodiaceae, Poaceae, *Artemisia* and *Plantago*, point to the intensification of agricultural practices, testified by the continuous presence of Cannabaceae and cereals. Surprisingly, *Olea* shows low values, although the local olive trees cultivation in this period is reported by historical sources. After 1500 cal. BP, the human impact became the dominant factor shaping the landscape, causing a further decrease in the natural arboreal cover, with reduction or even disappearance of many tree taxa. Nevertheless, the landscape was not treeless. In fact, there was an outstanding exponential growth of *Olea*, related to cultivation (Di Rita and Magri, 2009). These dynamics clearly outline the establishment of the modern landscape features, showing the progressive dedication of this territory to olive cultivation, which is now the main agricultural activity in the Salento region.

Lago Salso

Palaeoenvironmental studies in the coastal side of the Tavoliere Plain documented the presence throughout the Holocene of a lagoon (Laguna di Salpi) that during the phases of its maximum extension occupied a wide area, some 40 km long, beside the Adriatic Sea (Caldara et al., 2002). Since the middle Holocene, this coastal basin underwent successive modifications (Boenzi et al., 2001; Caldara et al., 2002), which led to the formation of several coastal lakes. Lago Salso was one of these lakes (site 20 in Fig. 1), located south of the coastal city of Manfredonia until its definitive disappearance at the beginning of the 20th century due to reclamation works. The chronology of the core CN3, collected 1 km apart from the settlement of Coppa Nevigata, is based on 9 radiocarbon dates carried out both on the organic content of the sediment and on *Cerastoderma* shells. The vegetation history of the area is characterized by three main vegetation phases (Di Rita et al., 2011). Between 6350 and 4050 cal. BP the landscape was characterized by a marshland, dominated by *Salicornia* s.l., and *Ruppia*, probably surrounded by an evergreen scrubland, mainly composed of *Olea*, *Pistacia* and *Phillyrea*, while extensive broadleaved forests were located at higher elevations inland (Fig. 2). Major fluctuations of the salt-marsh vegetation (*Salicornia* type and *Ruppia maritima*) have been related to the fluctuating extent of the Salpi Lagoon, possibly modulated by solar activity (Di Rita, 2012). Between 4050 and 3800 cal. BP, marked environmental transformations occurred in the landscape: i) at a local scale, a transition from a near-closed lagoon to a lake, starting ca. 4050 cal. BP, is well documented by the rapid disappearance of *Ruppia* meadows, replaced by reed vegetation composed by grasses and sedges, and the progressive decrease of salt-marsh vegetation (*Salicornia* type) coupled with a reduction of salt-marsh foraminifers, disappearing around 3700 cal. BP; ii) at a regional scale, an abrupt deforestation trend involving almost all the broadleaved vegetation is recorded starting around 4000 cal. BP.

After 3800 cal. BP the pollen diagram is interrupted due to a very low pollen concentration in the samples. However palaeovegetational information for the time interval 3500-3200 cal. BP is provided by pollen analyses from core CN5, some 800 m from CN3 (Di Rita et al., 2011). The CN5 pollen record documents a deforested landscape characterized by a strong reduction of both the deciduous and evergreen components of the arboreal vegetation. Anthropogenic markers (cultivated, ruderal and pastoral plants such as cereals, Urticaceae and *Plantago*) were very abundant and indicate that by 3500 cal. BP the southern slope of the Gargano headland was already heavily deforested, as it is today. These results suggest that the 4000 cal. BP vegetation opening had a long-lasting effect, exacerbated by intense local human activity. In the last hundreds of years, the sedimentary basin had freshwater conditions with marshy vegetation characterized by sedges and freshwater aquatic taxa. However, a peak of *Salicornia* type suggests that salt-marsh vegetation was probably still located by the sea before the reclamation work of the 19th century.

Lago Battaglia

Lago Battaglia (site 21 in Fig. 1) is a dried out coastal lake. Pollen analyses were carried out on the sediments of a 5.50 m deep core (BAT1) collected in the central part of the former basin (Caroli and Caldara, 2007). The chronological framework, provided by six AMS radiocarbon dates (one date rejected), encompasses the last 6000 years. Between approximately 6000 and 4000 cal. BP, the landscape was characterized by forest conditions with both evergreen and deciduous vegetation. The Mediterranean evergreen vegetation was mostly distributed along the coastline, while mixed deciduous forests extended at higher elevations on the Gargano headland. At around 4000 cal. BP this forested phase was interrupted by a temporary decrease in the arboreal vegetation, mainly involving broadleaved trees and *Pinus*, despite a coeval important increase in *Juniperus* (Caroli and Caldara, 2007). This process is interpreted as a result of a climate change towards drier conditions. When the vegetation recovered at around 3500 cal. BP, there was a remarkable expansion of *Pinus*, probably *Pinus halepensis*, which is now a very important element of the landscape in the northern sector of the Gargano headland.

The human impact on vegetation seems to have occurred since about 2700 cal. BP, determining a more or less progressive opening of the landscape, especially marked during the Roman period. After a new arboreal vegetation development between ca. 1500 and 1000 cal. BP, mainly related to increases in *Pinus* and *Juniperus*, the sequence records a final deforestation (Caroli and Caldara, 2007).

Lake Palu

Lake Palu (site 22 in Fig. 1) is situated in a sinkhole near the Adriatic coast, ca. 10 km south of the town of Rovinj (Istria, Croatia). The pollen sequence is provided with only one date, but on the basis of the palynological evidence Beug (1977) suggested an age of five millennia. The lower part of the sequence shows the dominance of forest vegetation, substantially characterized by deciduous oak woods rich in mesophilous elements, especially *Fagus*, *Abies* and *Picea*. In the middle part of the record, after the uncalibrated radiocarbon date 4490 ± 125 BP, an increase in the mesophilous component dominated by beech is found. A parallel development of riparian vegetation is recorded, with an expansion of *Salix*, followed by a marked increase in *Alnus*. Locally, the site experienced a distinct environmental change from freshwater conditions, mostly represented by *Myriophyllum* and *Nymphaea*, characterizing the lower part of the sequence, to brackish conditions with *Ruppia* in the upper part. The first definite hints for human activities, which caused a change in vegetation, are due to the beginning of the Roman colonization in Istria, during the first two centuries BC. As clearly shown in the pollen sequence, the human activity produced forest clearance mostly involving deciduous oak forest. This process allowed the evergreen trees and shrubs to develop in a wide maquis, mainly consisting of *Phillyrea* and *Quercus*. A noteworthy spread of *Juniperus* is the result of degradation due to clearance and grazing. The sequence ends with an important expansion of the *Phillyrea* maquis, partly replacing the juniper scrublands (Beug, 1977).

Lake Vrana

Lake Vrana (site 23 in Fig. 1) is a large and deep karstic lake on the northern Adriatic Island of Cres (Croatia). The chronological framework of the 5 m deep core is provided by four radiocarbon dates dating back to the last 17,500 years (Schmidt et al., 2000). The vegetation history of the late glacial period was characterized by high percentages of *Pinus* and *Betula*, accompanied by low frequencies of many deciduous tree taxa. After a temporary marked increase in herbs during the Younger Dryas, in the early Holocene a semi-open landscape developed, dominated by grasses (Fig. 2). *Pinus* and deciduous trees, such as oaks, *Betula*, *Fraxinus*, *Corylus*, *Ulmus* and *Tilia*, were the main components of the arboreal vegetation.

A further expansion of deciduous oaks, recorded at ca. 8000 cal., was accompanied by an appreciable increase in *Fagus*. According to Schmidt et al. (2000), these dynamics would point to the formation of the beech-rich belt currently dominating the mountain ranges in Istria and Dinarides.

At around 6000 cal. BP the arboreal vegetation underwent an important change, interpreted by the authors as caused by human activity: a degradation of the oak-dominated forest favoured a spread of *Juniperus* scrublands. At the same time a continuous presence of cereals, *Plantago*, *Olea* and *Carpinus betulus* was recorded.

After 4300 cal. BP a new expansion of the evergreen oak forest was recorded. According to the authors, evergreen oaks took advantage by both forest clearance and an increase in summer drought.

The upper part of the sequence shows the change from the Illyrian to Roman influence in the northern Adriatic region. According to Beug (1977), this transition is indicated by the onset of the curves of *Juglans* and *Castanea*, introduced for cultivation by the Romans. The last phase of the sequence shows a forested landscape dominated by mixed evergreen and deciduous oak woods, which experienced an important degradation, as indicated by a new spread of *Juniperus*. The increase in *Olea* and *Vitis* at this time indicates cultivation (Schmidt et al., 2000).

Malo Jezero

Malo Jezero (site 24 in Fig. 1) is a karstic lake located in the island of Mljet, south Dalmatia, Croatia. The site is the westernmost lake of a complex of two lakes originated in two karstic Pleistocene poljes flooded during a Holocene sea transgression. The lakes are currently connected to the Adriatic Sea through a narrow canal. The chronological framework is provided by 11 radiocarbon dates and one tephra layer, dating the pollen sequence to approximately the last 9500 cal. BP (Jahns and van den Bogaard, 1998).

Between ca. 9500 and 8000 cal. BP, the vegetation history was characterized by mixed deciduous oaks woodland, with sparse presence of evergreen taxa (Fig. 2). Between ca. 8000 and 6300 cal. BP, the dense oaks woodland was enriched by *Juniperus*, *Phillyrea* and other evergreen elements. However, the deciduous component, mostly represented by oaks, *Carpinus betulus*/*Ostrya*, *Corylus* and *Fagus*, was still dominant. Around 6300 cal. BP an expansion of *Quercus ilex* is recorded, pointing to the formation of a dense holm oak forest, which is considered to be the natural vegetation of the Dalmatian coast. Between 5200 and 3300 cal. BP a decline of *Juniperus* occurred with an increase in *Erica*. It was interpreted as either the result of increasing land use practice (burning and/or grazing), or the development of natural coastal vegetation, since *Erica arborea* represents an important native coastal species of the central Mediterranean region.

The upper part of the sequence is clearly influenced by human activity: the development of *Pinus* forest is interpreted as the possible result of the introduction of *Pinus halepensis* by Greek and/or Roman settlers. This vegetation type dominates the modern landscape in the island of Mljet. The pine plantations partly replaced the natural evergreen oaks forests. Along with the increase of *Pinus*, *Juglans* shows a continuous presence, *Olea* displays increasing values, and sparse records of *Ceratonia* appear for the first time. The records of cereals and *Vitis* provide evidence for cultivation. Besides, an expansion of *Juniperus* is interpreted as indicative of possible use of the land for pasture (Jahns and van den Bogaard, 1998).

Lake Voulkaria

Lake Voulkaria (site 25 in Fig. 1) is located in the coastal area of the Acarnania region, western Greece. The lake is connected to the Ionian Sea by a narrow artificial canal. The chronological framework is based on 15 dates, dating back to the last 10,500 cal. BP. The vegetation history of the area is characterized by the dominance of deciduous oaks throughout the Holocene (Jahns, 2005). The accompanying partners of this deciduous oaks woodland, however, varied considerably along the millennia (Fig. 2).

Between 10,500 and 8300 cal. BP, the deciduous oaks are accompanied by significant amounts of *Pistacia*, an important element of the still semi-open landscape of the early Holocene.

Between 8300 and 5500 cal. BP a decrease in *Pistacia* vegetation was coupled first with a development of deciduous taxa (mostly *Carpinus betulus*/*Ostrya*, *Fraxinus* and *Corylus*), and then with an increase in *Erica*. Between 5500 and 2900 cal. BP, there was a slight decrease in the deciduous oak cover, favouring the development of evergreen vegetation, mostly represented by *Phillyrea* and *Quercus*. According to Jahns (2005), this process would be the main result of increased human impact in the area. The end of this vegetation phase was marked by a sedimentary change, due to the deposition of a "brown layer", between ca. 2900 and 2800 cal. BP. This was interpreted as an unclear erosional event possibly related to a tsunami (Vött et al., 2008).

After this event, the vegetation history shows a further important increase of the evergreen component, mostly characterized by a temporary expansion of *Phillyrea*, which became the dominant taxon of the landscape. The human impact in this period is particularly strong, due to the foundation of the nearby Classical city of Palairos.

Between ca. 2500 and 2200 cal. BP the Acarnania region was probably less populated than in the preceding phases, favouring the regeneration of the deciduous woodland. However, settlement activities in the area are documented by the significant presence of *Olea* and *Juglans* that according to Jahns (2005) must be regarded as cultivated. The Roman period was characterized by a slight increase in evergreen vegetation, despite a decrease in *Olea*. The most important process of the final vegetational phase was a new increase in *Olea* since approximately the Byzantine times.

Alikes Lagoon

The study area is the Alikes wetland (an old salt pan), located in the northern part of Zakynthos Island (site 26 in Fig. 1). The Alikes Lagoon is separated from the Ionian Sea by a low relief sand barrier, while its communication with the open sea is limited to a short and narrow inlet. The chronology of the core is based on 7 radiocarbon dates on *Cerastoderma* shells, providing an age for the record spanning approximately from 8500 to 5000 cal. BP (Avramidis et al., 2012).

Between 8540 and 8100 cal. BP, the pollen record indicates open vegetation with sparse presence of trees and shrubs (Fig. 2). The limited presence of warm temperate taxa requiring moist soils habitat (*Alnus*, *Salix*, *Platanus*, *Juglans*, *Vitis*) together with the presence of coniferous communities from higher altitudes (mainly Mediterranean pine forests together with *Ulmus*, *Carpinus orientalis*/*Ostrya*, *Tilia*, *Acer*, *C. betulus* and *Corylus*) suggest that the study area was characterized by low precipitations. The most severe change within this period was a decline of the forest cover between 8300 and 8100 BP, possibly reflecting the climatic deterioration corresponding to the 8.2 event. Between 8100 and 7800 cal. BP, the landscape experienced a reafforestation process, with the increase of several arboreal taxa, the most important being *Pinus*, *Quercus*, riparian trees (*Alnus*, *Salix*, *Platanus*) and Mediterranean trees and shrubs (*Olea*, *Pistacia*, *Phillyrea*). Between 7800 and 6300 cal. BP, the temperate and wet arboreal taxa decreased. Corresponding increases in *Ephedra*, Caryophyllaceae, Ranunculaceae and other herbs suggest an expansion of dune vegetation and increased aridity. Starting from 6300 BP, the pollen record shows parallel increases of wet environments and Mediterranean arboreal communities, probably related to the prevalence of mild and moist winters with dry and warm summers. However, an expansion of *Olea* may be attributed to human activity (Avramidis et al., 2012).

DISCUSSION

The coastal pollen records so far published from the central Mediterranean region describe with satisfactory continuity the history of vegetation of the last 7000 years, that is after the major sea level rise and marine transgression of the early-mid Holocene (Lambeck et al., 2011 and reference therein). Conversely, the time interval 13000-7000 cal. BP is represented only by a limited number of records and needs further studies (Fig. 2). In particular, the lateglacial fluctuations are recorded in only two records, one from central Italy (Pesce Luna) and one from Croatia (Lake Vrana).

The pollen records between 7000 cal. BP and the present time reveal a rather diverse composition and structure of vegetation. The simplified scheme of figure 2 shows that Sardinia and Corsica were mainly characterized by evergreen vegetation with *Erica*, in W Italy mixed deciduous and woodlands alternated with marshland episodes, in S Sicily and Malta mixed evergreen woodland/scrubland with *Olea* and *Pistacia* interchanged with grasslands, in SE Italy evergreen forests/woodlands dominated the landscape, in the coasts of the W Balkan Peninsula a mixture of deciduous and evergreen woodlands with *Juniperus* and *Phillyrea* scublands were found. This mosaic of vegetation types is to be ascribed partly to the diversity of climate conditions along the central Mediterranean coasts, and partly to the previous history of plant populations.

Within these vegetation types, several fluctuations are recorded during the last seven millennia. In particular it is worth noting that many sites underwent vegetation changes in specific time intervals (Fig. 2). For example, between 5500 and 5100 cal. BP in three sites located in Corsica and W Italy a marshland formed, followed by mixed woodlands and *Alnus* carrs (Reille, 1992; Colombaroli et al., 2007; Di Rita et al., 2010). Between 4500 and 4000 cal. BP, a clear opening of the forest is recorded in S Sicily and SE Italy, which is not matched by a similar trend in the sites of the Balkan Peninsula.

The most widespread vegetational change, recorded by 13 pollen diagrams out of 16, took place around 2000 cal. BP. It corresponds to a clear opening of the vegetation with an overall increase in cultivated elements, and is generally considered the result of a marked amplification of human impact by the Romans. A clear human action is documented in some of these sites, for example at Lago d'Averno, where the Romans built the *Portus Julius* in 37 BC (Grüger and Thulin, 1998). However, the extensive nature of this vegetational change may also suggest the possibility of a co-occurrence of factors, including human impact and climate change (e.g., Reale and Dirmeyer, 2000).

In all the sites, a general increase of evergreen vegetation is found along the Holocene (Sadori et al., 2011) leading to the formation of scrublands and open landscapes in many coastal areas especially in the last two millennia, when abundant signs of cultivations are also evident.

This observation inevitably leads to the importance of deciphering the main factors that have threatened the Mediterranean coastal vegetation during the Holocene. These factors may be ascribed to three main categories, including climate, geomorphic processes, and human impact, usually showing strong synergistic interactions and interdependence. The pollen records from the central Mediterranean Basin provide useful information to assess the possible influence of these factors in past environmental changes.

Climate change

The intensity of climate impact on the ecosystems in the Mediterranean Basin, where the vegetation shows a particularly rapid response to short-term climate perturbations, is related to the strategic position of the Basin, intermediate between climate systems of the high latitudes, mainly influenced by the North Atlantic Oscillation, and of the lower latitudes, strongly influenced by ITCZ (Inter-Tropical Convergence Zone) shifts. Variations in these climate systems tend to induce changes both in physical variables, including temperature, rainfall, and solar radiation, and in statistical variables, such as storm frequency and severity, as well as precipitation frequency and intensity. The effects of these changes may be harmful to the unstable coastal ecosystems, especially in the light of catastrophic predictions developed by a number of climate models for the next future (e.g. Nicholls et al., 1999; Johns et al., 2003).

Pollen analysis is a valuable tool to detect vegetational processes related to climate changes and to assess their spatial and temporal importance. For example, the pollen records from the Central Mediterranean coastal areas show clear fluctuations in composition (e.g. development of maquis vegetation), physiognomy (deciduous vs. evergreen elements), and structure of vegetation (degree of forestation), most likely related to climate changes, at least before extensive human impact. In particular, the vegetation response to the main climate fluctuations of the lateglacial and early Holocene, although poorly investigated in coastal areas, seems very marked (Fig. 2). The vegetation changes recorded in the Pesce Luna record (Milli et al., 2012), documents the development of open landscapes with mixed woods dominated by *Pinus* with xerophytes communities, during the cold and arid interval of the Younger Dryas, and by deciduous trees with marshlands during the warm and humid phases of the lateglacial and early Holocene. An open landscape with *Pinus* formations is also recorded at Lake Vrana during the Younger Dryas, while mixed deciduous woodlands, with a significant persistence of *Pinus* communities, developed from the beginning of the Holocene until ca. 6000 cal. BP (Schmidt et al., 2000). The attribution of vegetation changes to short climate events recognized for the lateglacial period and early Holocene (e.g. Intra-Allerød cold period, Preboreal Oscillation, 8.2 ka event) is really difficult, mainly due to the scarcity of data and the interactive action of multiple factors that may overshadow the signal in coastal pollen records. Conversely, the influence of these oscillations on the vegetation development can be recognized in inland sites (Magny et al. 2006; Di Rita et al., 2012b; Joannin et al., 2012).

Another vegetation change possibly induced by climate change may be recognized in a number of coastal sites south of 43°N (Crovani, Gorgo Basso, Biviere di Gela, Lago Alimini Piccolo, Lago Salso, Lago Battaglia, and Salina Bay; Fig. 1), which show a temporary drop of evergreen forest cover around 4.2 ka BP (Fig. 2). This change may be related to a progressive time-transgressive expansion of a North African high pressure front, possibly linked to a latitudinal displacement of the ITCZ (Di Rita and Magri, 2009; Di Rita et al., 2011). This climate fluctuation is especially interesting because it appears contemporary with climate changes recorded by different proxies in an extensive longitudinal belt, including not only the Mediterranean regions (e.g., Bar-Matthews et al., 1997; Drysdale et al., 2006; Fiorentino et al., 2008; Carroll et al., 2012) and the Near and Middle East (Weiss et al., 1993; Cullen et al., 2000), but also Africa (Gasse, 2000), Asia (Yasuda et al., 2004), and America (Marchant and Hooghiemstra, 2004).

Shifts of the ITCZ may have had a significant impact in the vegetation development of Malta and southern Sicily during the mid-Holocene, triggering the expansion of *Pistacia*-dominated woodland formations at Burmarrad (Djamali et al., 2012), Gorgo Basso (Tinner et al., 2009), Lago Preola (Calò et al., 2012) and Biviere di Gela (Noti et al., 2009). According to Djamali et al. (2012) a southward migration of the ITCZ occurred from 7000 cal. BP (Fleitmann et al., 2007; Incarbona et al., 2008; Djamali et al., 2010), which may have favoured the eastward movement of the North Atlantic cyclonic systems, conveying humid air masses into the central and eastern Mediterranean through the westerlies, and determining a shortening of the dry season with the development of evergreen vegetation.

Geomorphic processes

Sea level changes can produce a multitude of major consequences threatening directly and/or indirectly the environmental maintenance of the coastal ecosystems. The current need to assess at global and regional scales the future sea level trend and its effects on densely populated coasts has brought this subject to the forefront of climate and geological research (IPCC, 2007). Nicholls et al. (1999) predict that a global sea-level rise of 1 m would eliminate 46% of the world's coastal wetlands, which would experience increased flooding and would undergo irreversible losses where their capability to migrate vertically and horizontally, in response to sea level variation, is hampered. Another hazard for coastal environments, exacerbated by the sea level rise, is the underground saltwater intrusion in the coastal unconfined aquifers (Ranjan et al., 2006), especially in flat areas (Ataie-Ashtiani et al., 1999).

Pollen analysis represents a valuable tool to assess the influence of sea level variations on different coastal areas. In fact, the herbaceous and aquatic vegetation of coastal environments responds directly to the salinity changes related to sea level changes. The interpretation of the variations of halophytes and freshwater taxa in pollen records, and their comparison with other sites and proxies, may help detect vegetation dynamics related to sea level changes at a local, regional and supra-regional scale. To that purpose the comparison of pollen data with plant macrofossils, diatoms, foraminifers, ostracods and molluscs is especially useful. For example, in the Alikes Lagoon (Avramidis et al., 2012), the foraminifera record, coupled with sedimentological and pollen data has allowed reconstructing the marine influence on the lagoon and possible local tectonic activity.

Plant macrofossils have proved useful complementary indicators of water level and salinity changes in the coastal basins of Lago Alimini Piccolo (Primavera et al., 2011) and Stagno di Maccarese (Di Rita et al., 2010; 2012a; Milli et al., in press). Combined diatom and pollen data have proved to confirm each other at Lago di Massaciuccoli, where over the entire sequence Chenopodiaceae was significantly correlated with the abundance of saltwater diatoms (Marchetto et al., 2008).

An interesting case study dealing with salinity changes in a coastal marshland is the evolution of the Lago Salso area (site 20 in Fig. 1), where regular fluctuations of halophilic vegetation are recorded by pollen between 6350 and 4000 cal. BP (Di Rita, 2012). A comparison of salt-marsh pollen indicators (*Salicornia* type and *Ruppia* maritima) with the ^{10}Be dataset from the Greenland ice core GISP2 suggests a close correspondence of the extent of the coastal marshland with solar activity. In particular, the Tavoliere salt-marsh appears to have contracted during the arid/warm phases associated to maxima of solar activity and to have expanded during the wet/cold phases of solar minima. This coastal area, characterized by very flat topography and arid climate appears to be very sensitive to even minor hydrological and climate changes, which may have been the main factors determining extensive environmental transformations during the Holocene and possibly repeated abandonments of the local human coastal settlements, at least during the Neolithic.

Other geomorphic processes that may affect the coastal vegetation and be recorded in pollen diagrams are related to river deltas. For example, the pollen record from Ostia, complemented by sedimentological and malacological analyses, describes with much precision the evolution of the Tiber delta area from around 3900 cal. BP (Bellotti et al., 2011).

Deep landscape changes related to geomorphical and hydrological processes are also recorded in Stagno di Maccarese, north of the Tiber delta (Di Rita et al., 2010; 2012a). In the pollen record of this site a clear development of marshy environments is recorded between 5500 and 5100 cal. BP, followed by the establishment of dense alder carrs. Similar dynamics are replicated in other coastal sites located in the western sector of the central Mediterranean, both in the Tyrrhenian margin (Colombaroli et al., 2007) and Corsica (Reille 1984; 1992) (Fig. 2). These dynamics are consistent with hydrosere successions inside the basins, possibly influenced by common geomorphic factors affecting coastal and estuarine ecosystems such as: sea level variations, sandy barriers formation, salinity and sedimentation changes, and riverine inputs.

Human impact

The long human history of frequentation of coastal areas has always been associated with an intensive exploitation of the natural ecosystems. The main threats are related to the use of groundwater for irrigation or drinking water supply, so increasing the risk of desertification, which is already high in the Mediterranean basin (van der Meulen and Salman, 1996). Overexploitation has also affected the Mediterranean vegetation through agricultural activities on sandy dunes (e.g. grazing, hunting, collecting fruits and firewood, and cropping) since the first human settlements, with the most important effect of changing the primary coastal maquis down to secondary maquis, garrigue and sparsely vegetated or bare soil (van der Meulen and Salman, 1996). In addition, in coastal environments many non-indigenous species have been accidentally transported or intentionally introduced by human activities and have established populations that have had major ecological consequences, threatening the native communities.

The pollen records from the central Mediterranean Basin describe a long history of exploitation of coastal ecosystems and its local intensification in historical times, determining deep and often irreversible modifications of the landscape.

According to Tinner et al. (2009) and Djamali et al. (2012) traces of human presence can be recognized in the pollen diagrams from Sicily and Malta since at least 7500 cal. BP, when archaeological data testify for the diffusion of the Neolithic culture. More pronounced evidence is found after ca. 6000 cal. BP with a gradual decline of tree pollen. However, in the coastal Tavoliere Plain, where abundant archaeological records document a diffused agricultural practice already before 7500 BP, the human action appears a negligible factor in the vegetation development, which was primarily determined by alternate phases of expansion and retreat of the coastal wetland (Di Rita et al., 2011). In the same area, after the 4 ka BP drought event, the human impact during the Bronze age probably played an important role in maintaining an open landscape.

During the Bronze age, changes of vegetation features clearly ascribable to human presence are found in most coastal sites. At Lago Alimini Piccolo an increase of *Olea* suggests management and exploitation of local wild olive trees (Di Rita and Magri, 2009); at Massaciuccoli an opening of woodland accompanied by high amounts of *Vitis* are interpreted as the evidence for an early agricultural practice favouring the native grapevines (Mariotti Lippi et al., 2007); frequent occurrences of *Erica* suggest burning or grazing at Malo Jezero (Jahns and van den Bogaard, 1998), while in Corsica a decrease of *Erica* would appear to reflect forest clearing partly influenced by human activity (Reille, 1992).

In historical times the effects of the human demographic increase, coupled with agricultural development, technological evolution and related enhancement of trading system, determined major changes in the coastal Mediterranean ecosystems, as clearly reflected in most of the pollen records by general reductions of the native forest cover (Fig. 2).

At Lago d'Averno, for example, the dense evergreen forest that covered the area at the time of the Greek colonization of the area, underwent a terrific Roman clearance, documented also by historical sources (Grüger and Thulin, 1998). Clear signs of extensive plantations are found in many pollen records: at Mistras in Sardinia there is an increase of *Quercus suber* around 2000 cal. BP, testifying for cork exploitation (Di Rita and Melis, submitted), at Lago Alimini Piccolo in Apulia an extraordinary expansion of *Olea* occurred since the Bizantyne domination (Di Rita and Magri, 2009), at Saleccia in Corsica (Reille, 1992), Malo Jezero in Croatia (Jahns and van den Bogaard, 1998), and Massaciuccoli in Italy (Colombaroli et al., 2007) *Pinus* was planted in the last few centuries.

The human activity has in some cases radically changed the land use of coastal areas. For example, the pollen records from Stagno di Maccarese (Di Rita et al., 2010), Stagno di Ostia (Bellotti et al., 2011), and the Ombrone Plain (Biserni and van Geel, 2005), show the signs of the implantation of salt-works in Roman times. In southern Sicily, historical sources and pollen data concur in showing that the conversion of woodlands and scrublands into a very open cultural landscape was primarily the consequence of human land use related to the Greek colonization.

CONCLUSIONS

In this study, we have reviewed twenty-six pollen records from coastal areas, in order to refine our knowledge about the vegetation history in the central Mediterranean region. These records have been compared and discussed with the purpose of recognizing, interpreting and correlating similar palaeoecological dynamics, as well as detecting climatic changes and anthropogenic processes of supraregional interest.

The main outcome of this work is the recognition of a variety of vegetational dynamics in a wide range of geomorphological and climate situations. Some vegetation changes are more or less contemporary in many sites. For example, 13 out of the 16 sequences recording the vegetation features around 2000 cal. BP show a clear landscape change at that time. This may be due to the expansion of the Roman domination, but also to climate change (e.g., Reale and Dirmeyer, 2000), or a combination of the two factors.

Other vegetation changes involved only one sector of the central Mediterranean Basin. For example, in the sites of the Tyrrhenian side of the Italian Penisula and Corsica a clear contemporary development of marshy environments is recorded between 5500 and 5100 cal. BP, followed by the establishment of dense alder carrs. This landscape change may have resulted from complex processes related to sea level variations, freshwater inputs and sedimentological changes. In other sites, located south of 43°N in Sicily and S Italy, a time-transgressive pattern of forest decline, mostly affecting the evergreen vegetation, is observed ca. 4.5 to 3.9 cal. BP, with a geographical progression from SW to NE. This pattern may be due to the temporary displacement of a high pressure cell from north Africa, linked to global changes of climate modes.

Also the responses of vegetation to human activity have been different from site to site, depending on vegetation physiognomy and climate conditions, as well as on times and modes of anthropization. For example, the cultivated taxa were different from site to site, often reflecting the local natural plant resources, initially exploited by man, and successively managed and cultivated. This is the case of *Olea* in southen Apulia and in Sicily, *Vitis* in Tuscany, cereals in the Tavoliere Plain, and *Quercus suber* in Sardinia and Corsica. In many cases it is possible to trace back a long-term persistence of the same land use in a given area, which lasts up to the present time.

These results lead to some general conclusions:

The variability of the coastal vegetation in the central Mediterranean Basin, influenced by different geomorphic situations, climate conditions, biological processes and human history, makes it impossible to define a pollen stratigraphical scheme valid for the entire area during the last thousands of years, although there is now a general compelling case for subdividing the Holocene into stratigraphic units (Walker et al., 2012).

The costal pollen records from the central Mediterranean region significantly improve our knowledge on the measure of human impact on the territory during the transition from a nature-dominated to a man-dominated landscape. Our results indicate a general and progressive anthropization trend of the vegetational landscape since the Neolithic, evolving with different times and modes from site to site. At the same time, these data show that in many cases human populations adapted their activities to the locally existing natural resources, for example by exploiting native plant taxa, or transforming natural coastal wetlands in saltworks.

Coastal pollen records usually show major transformations of the vegetational landscape, characterized by more or less rapid transitions, indicating a remarkable environmental instability, related to both natural and human-induced processes. A main practical issue may derive from this feature. Considered within the last thousands of years, the modern vegetational situation appears a snap-shot, destined to new, abrupt and dramatic future changes. The possible rapid loss of large coastal natural habitats (e.g. coastal wetlands), may induce a loss of both flora and fauna. Therefore, palaeoenvironmental studies in coastal areas, which are extremely precious biodiversity reservoirs, are of fundamental importance, as they may eventually lead to estimate the degree of vulnerability of coastal ecosystems, and suggest plans for appropriate conservation actions.

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