Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: a 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy

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Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: a 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy

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A HOLOCENE RESEARCH PAPER

Abstract: Pollen analysis from Lago Alimini Piccolo provides the first record of mid- and late-Holocene vegetation history of a coastal area in the easternmost region of southern Italy (Salento Peninsula). Terrestrial pollen taxa document expansions and declines of the Mediterranean forest, in relation to human activity and climate changes. Between 5200 and 4350 cal. BP a dense evergreen oak forest dominated the landscape; then a distinct opening of the forest is recorded (4350–3900 cal. BP). A new forest expansion (3900–2100 cal. BP) is characterized by an increase of *Olea* and evergreen shrubs, indicating a development of mediterranean climate conditions and increasing human disturbance. The Roman occupation period (2100–1500 cal. BP) shows a significant opening of the forest, expansion of halophytes and modest values of *Olea*. After 1500 cal. BP human impact causes a further decrease of the natural woodland in favour of an extraordinary expansion of *Olea*. The vegetation development at Lago Alimini Piccolo, interpreted in the light of other pollen records, provides new insights into climate evolution and evergreen vegetation development in the central Mediterranean region: (1) a temporary mid-Holocene deforestation at 4000 cal. BP, involving many Italian sites south of 43°N, was possibly caused by drought associated with an expansion or northward displacement of the North African high pressure zone; (2) the Bronze Age increase of *Olea*, coupled with a widespread increase of Mediterranean shrubs, suggests management of wild trees, while the beginning of intensive cultivation of olive trees is only found after the Roman time.

Key words: Lago Alimini, Italy, pollen analysis, Holocene, drought, deforestation, vegetation history, *Olea*, 4000 cal. BP event, wind direction, Mediterranean.

Introduction

Only a few Holocene pollen records are currently available in southern Italy. In particular, coastal areas require further study, as they are biodiversity hotspots. At the same time they are very vulnerable areas, being characterized by a marked environmental instability, which makes their vegetation particularly sensitive to anthropogenic impact and climatic changes. In fact, in Mediterranean coastal areas, the arboreal cover, mainly composed of xerophitic communities, may be largely affected by aridification trends, especially where rainfall and edaphic factors are already limiting woodland formation (Maselli, 2004 and references therein). In addition, environmental instability may be amplified by geomorphic processes, sea level fluctuations and water salinity changes. Finally, pronounced landscape changes are produced by human activity, above all in the proximity of harbours that have been the crossroads of different civilizations through several millennia.

The aim of this paper is to reconstruct the vegetational and environmental history of the easternmost coastal area of Italy during the last six millennia by means of pollen analysis from Lago Alimini Piccolo, a lake located in the Salento Peninsula (Apulia region), the heel of the 'Italian boot'.

A second purpose is to compare the vegetational changes observed at Lago Alimini Piccolo with other records from the central Mediterranean area, in order to recognize, interpret and correlate similar palaeoecological dynamics of interregional interest, so contributing to the ongoing lively debates about three key topics: (1) a drought event recognized by several proxy data across the

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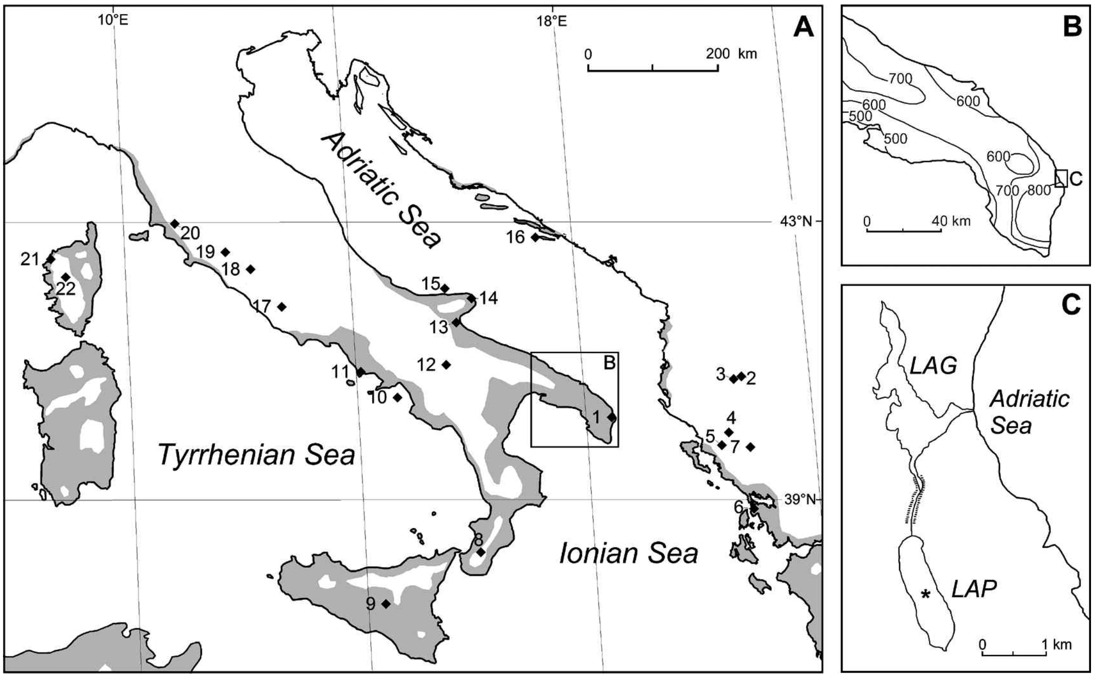

Figure 1 (A) Distribution of the potential Mediterranean sclerophyllous vegetation (in grey, modified from Bohn *et al*., 2000) and location of study sites south of 43°N considered in the text: 1, Lago Alimini Piccolo; 2, Lake Maliq (Denèfle *et al*., 2000); 3, Sovjan (Fouache *et al*., 2001); 4, Rezina (Willis, 1992b); 5, Gramousti (Willis, 1992a); 6, Lake Voulkaria (Jahns, 2005); 7, Ioannina I-284 (Lawson *et al*., 2004); 8, Canolo Nuovo (Schneider, 1985); 9, Lago di Pergusa (Sadori and Narcisi, 2001); 10, C106 (Russo Ermolli and di Pasquale, 2002); 11, Lago d'Averno (Grüger and Thulin, 1998); 12, Lago Grande di Monticchio (Watts *et al*,. 1996; Allen *et al*., 2002); 13, Lago Salso (Caldara *et al*., 2003); 14, Lago Battaglia (Caroli and Caldara, 2007); 15, RF93-30 (Oldfield *et al*., 2003); 16, Malo Jezero (Jahns and van den Bogaard, 1998); 17, Lago Albano (Lowe *et al*., 1996); 18, Lago di Vico (Magri and Sadori, 1999); 19, Lagaccione (Magri, 1999); 20, Lago dell'Accesa (Drescher-Schneider *et al*., 2007); 21, Crovani (Reille, 1992); 22, Lac de Creno (Reille *et al*., 1999). (B) Mean annual precipitation in the Salento Peninsula (redrawn from Ministero dei Lavori Pubblici, 1959). (C) Map of Lago Alimini Piccolo (LAP, Lago Alimini Piccolo; LAG, Lago Alimini Grande, * coring site)

Mediterranen Basin and Africa around 4000 cal. BP (eg, Dalfes *et al*., 1997; Gasse, 2000; Eastwood *et al*., 2007); (2) a mid- to late-Holocene increase in evergreen vegetation, widely recorded in the Mediterranean basin, and ascribed to either human activity (eg, Reille and Pons, 1992; Pons and Quézel, 1998) or climatic trends (eg, Yll *et al*., 1997; Jalut *et al*., 2000; Carrión *et al*., 2004); (3) the exploitation and cultivation of *Olea,* an emblematic tree of the Mediterranean natural environment (Jahns, 1993; Bottema and Sarpaki, 2003; Terral *et al*., 2004; Besnard *et al*., 2007).

Study area

Lago Alimini Piccolo (40°11′N; 18°26′E; 1 m a.s.l.) is the largest natural freshwater lake in Apulia (1.05 km^2), mainly fed by springs located in the southwestern side of the lake (De Marco *et al*., 1983). It is linked, by means of a narrow channel, to a brackish lake (Lago Alimini Grande), in turn connected to the Adriatic Sea (Figure 1).

According to Guerricchio and Zezza (1982) the basin occupied by the Alimini lakes is the result of interaction between tectonic movements, karstic and geomorphic processes, shaping the Plio-Pleistocene calcarenitic bedrock (Ciaranfi *et al*., 1988).

Geomorphological evidence and radiometric ages indicate that the area, after a period of uplift, has been tectonically rather stable since the last part of the middle Pleistocene (MIS 9) (Mastronuzzi *et al*., 2007). Along the Adriatic coast of the Salento peninsula there are rocky shores slightly sloping towards the sea and high cliffs. Adjacent to the Alimini lakes, for a length of about 3 km, there is a sandy shore bordered by inland dunes. Numerous traces of past sea level indicators along the coast are recognizable at different heights both above and below the present sea level, documenting Holocene sea level changes (Mastronuzzi *et al*., 1994).

The mean annual rainfall of the area varies between 500–600 mm and 800–900 mm within a distance of 15 km (Figure 1B). This feature may have had a considerable influence on the composition and structure of the vegetation, in response to even minor fluctuations of precipitation. From the bioclimatic point of view, the Alimini area is classified as Thermo-Mediterranean sub-humid (Blasi and Michetti, 2005), but is included in a mosaic of other classes, including a Thermo-Mediterranean dry bioclimate a few kilometres northward, and a Meso-Mediterranean sub-humid bioclimate southward. All the same, the potential natural vegetation of the region is transitional between two phytosociological alliances, *Quercion ilicis* and *Oleo-Ceratonion* (Curti and Lorenzoni, 1969). *Quercion ilicis* characterizes more inland areas, while the thermophilous communities of *Oleo-Ceratonion* are found both along coastal dunes and into the glades of the *Quercion ilicis* woodlands (Lorenzoni and Ghirelli, 1988). Moderate climate changes and/or vegetational degradation and restoration processes easily induce mutual transformations from one alliance into the other (Curti *et al*., 1976).

The modern vegetation of the area is highly degraded, and the natural arboreal cover is very limited. Extensive reclamation works, carried out in the first half of the twentieth century, considerably modified the natural landscape, which is now characterized by olive groves, cultivated land and stands of planted *Pinus halepensis* Mill. In the residual patches of *maquis* the dominant species is *Quercus calliprinos* Webb, mostly accompanied by *Olea europaea* L. var. *sylvestris* Brot., *Pistacia lentiscus* L., *Phillyrea latifolia* L., *Arbutus unedo* L., *Erica manipuliflora* Salisb., *Rhamnus alaternus* L., *Myrtus communis* L., *Ceratonia siliqua* L., *Calycotome spinosa* (L.) Link (Macchia, 1973; Marchiori *et al*., 1998). The shore of Lago Alimini Piccolo is occupied by lush reeds of *Phragmites australis* (Cav.) Trin. ex

Table 1 Radiocarbon dates

Lab. number	Material dated	Depth (cm)	$\delta^{13}C$ (‰ PDB)	^{14}C ages (yr BP)	Cal. ages (2σ) (yr BP)
Ua13189	organic sediment	30	−23.10	1105±85	1179–788
Ua12577	organic sediment	50	−20.76	2010±60	2003–1718
Ua12053	organic sediment	112	−21.88	2885±75	3162–2771
Ua12578	organic sediment	150	−17.46	3725±60	4079–3719
Ua12054	organic sediment	224	−25.61	4760±75	5607–5318

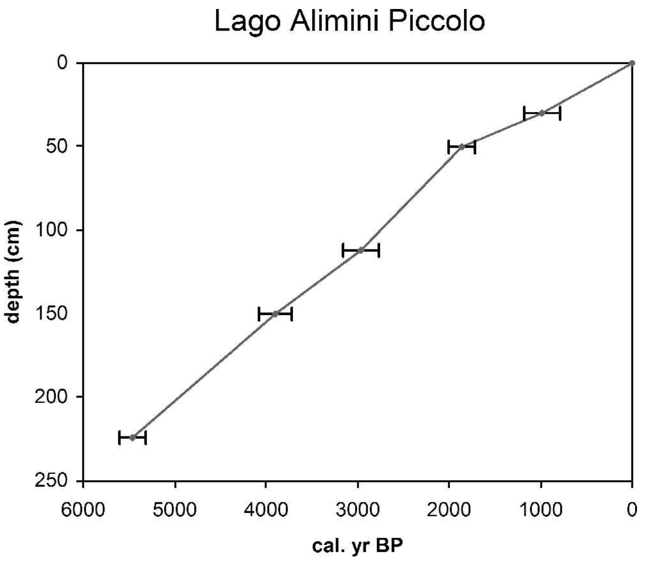

Figure 2 Lago Alimini Piccolo. Age–depth model for calibrated radiocarbon dates with 2σ confidence intervals. Age–depth modelling for Lago Alimini Piccolo

Steud. Lago Alimini Grande presents an abundant halophilic flora, with several species of *Plantago* and *Limonium* along its shore, and populations of *Ruppia maritima* L. in its brackish water (Marchiori *et al*., 1998).

The surroundings of the Alimini lakes record a long history of human settlement, documented by middle Palaeolithic, final Epigravettian/Mesolithic and early Neolithic finds (Piccinno and Piccinno, 1978; Milliken and Skeates, 1989). During the Bronze age (thirteenth–twelfth centuries BC) there is archaeological evidence of close contacts with the late Mycenaean civilization of Crete (Orlando, 1983, 1994). In the eleventh century BC the region was invaded by the Messapians, from Illyria, who withstood the Greek colonizers for a long time. The Greeks kept the city of Otranto, located 3.5 km southeast of Lago Alimini Piccolo, until 280 BC, when the Romans settled in the area, followed by Byzantines, Normans, Suebics, Angevins, Turks and Aragoneses, attracted by the strategic position of Otranto, a very important harbour connecting the Italian peninsula to the eastern Mediterranean countries.

Materials and methods

A sonar profile across Lago Alimini Piccolo, carried out with the aim of selecting a suitable drilling point, displayed a very flat bottom at a water depth of around 2 m. A 410 cm long core of lacustrine sediment was collected from the central part of the lake (Figure 1C) using a Russian corer. The recovered sediments mainly consist of clay and calcareous silts with levels rich in mollusc remains and organic matter.

Samples for pollen analysis were taken at 4 cm intervals throughout the core and chemically treated with HCl (37%), HF (40%) and NaOH (10%). A known amount of exotic *Lycopodium* spores was added to estimate pollen concentrations.

This paper presents the results of pollen analysis carried out on 57 samples collected between 8 cm and 232 cm depth. The remaining sediments did not provide enough pollen to be represented in diagrams. In the 53 samples exceeding 50% Arboreal Pollen (AP) the mean count was 502 terrestrial pollen grains, while in the four samples with more than 50% Non Arboreal Pollen (NAP) the mean count was 208 pollen grains.

The computer program Psimpoll 4.25 (Bennett, 2005) was used to plot the diagrams and calculate the calibrated timescale.

Two pollen types of *Quercus* were distinguished (van Benthem *et al*., 1984): *Quercus* evergreen type, including *Q. ilex* and *Q. coccifera*, and *Quercus* deciduous, which includes all deciduous oaks and possible occasional *Q. suber*, which is now living over 100 km from Lago Alimini Piccolo, *Q. cerris* and *Q. macrolepis*. *Ostrya*/*Carpinus orientalis* represents the pollen sum of the two species *Ostrya carpinifolia* and *Carpinus orientalis*. *Typha latifolia* pollen was distinguished from other Typhaceae, included in *Sparganium*/*Typha* group. *Limonium* type includes the pollen of *Limonium* and *Armeria*.

Microcharcoal analysis of the sequence was carried out in order to reconstruct the fire history of the area and the vegetation responses to fires. The analysis followed the procedures described by Clark (1982). 150 microscope fields were counted for each pollen sample. Microcharcoals smaller than 5 μm were excluded from the sum. *Lycopodium* spores were used to estimate microcharcoal concentrations.

Five AMS radiocarbon analyses (Table 1) were carried out on bulk sediment samples at the Ångström Laboratory, University of Uppsala. The radiocarbon dates were calibrated using the CALIB5.0.1 program (Stuiver and Reimer, 1993) with the IntCal04 (Reimer *et al*., 2004) and Marine04 (Hughen *et al*., 2004) calibration data sets and indicate that the base of the record has an age of about 5600 years. Considering the connection of Lago Alimini Piccolo to the Adriatic Sea through Lago Alimini Grande, a mixed marine/atmospheric calibration was applied to the samples with $\delta^{13}C > -25‰$, using a regional δR correction value of 118 ± 60, as suggested by Cattaneo *et al*. (2003). All dates are internally consistent and were used for age–depth modelling (linear interpolation of mid-points of the 2σ calibration range), indicating rather constant sedimentation rates, slightly decreasing after 2000 cal. BP (Figure 2).

Results

Pollen preservation was generally good. Excluding spores and non-pollen palynomorphs, 88 pollen taxa were identified, the highest number of terrestrial taxa per sample being 49 and the lowest 18. The number of indeterminable grains never exceeded 5%. Total pollen concentration varies between 4600 and 73 200 grains/g sediment.

The results of pollen analysis are presented as a percentage diagram (Figure 3) and a concentration diagram (Figure 4). In the

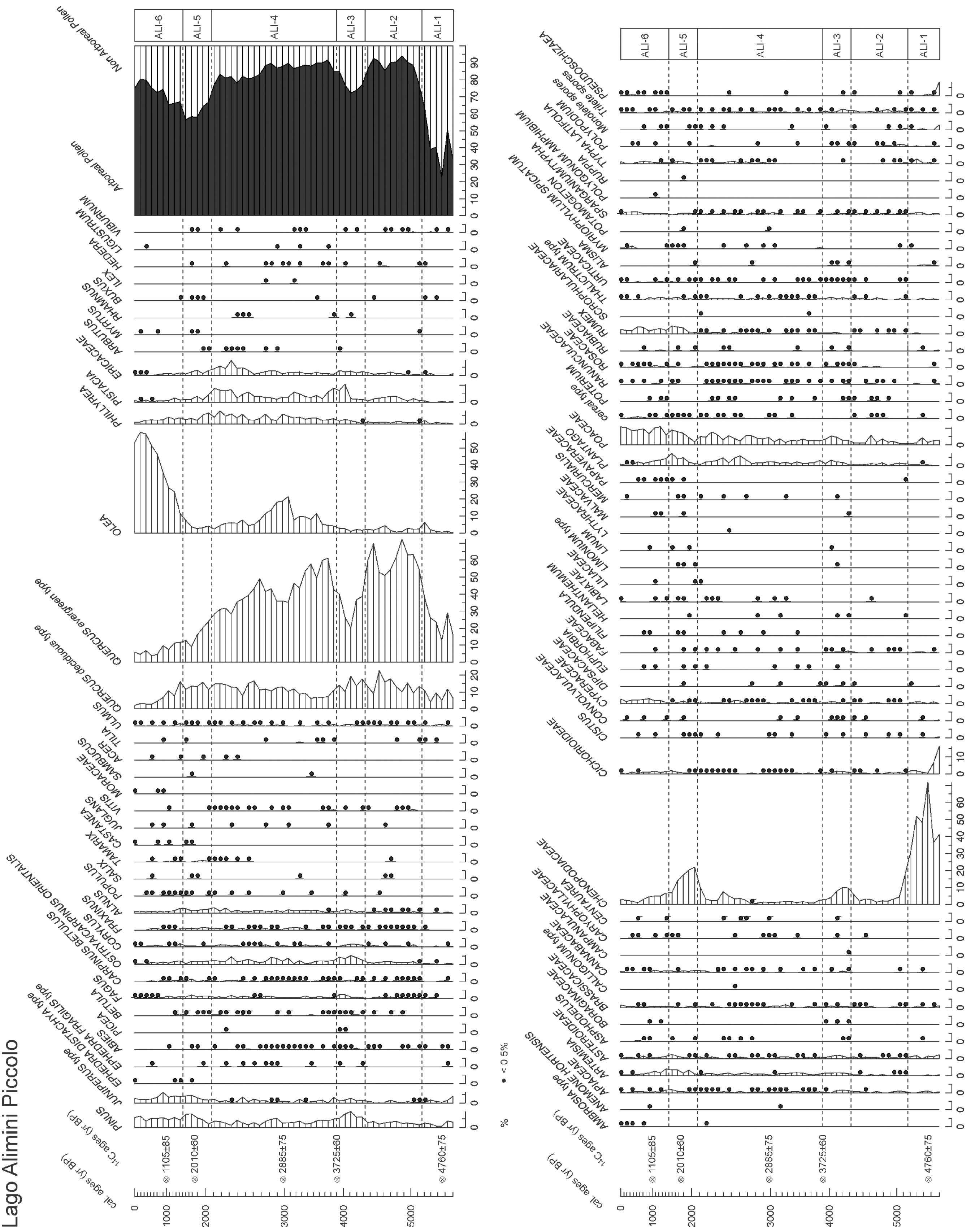

Figure 3 Lago Alimini Piccolo. Pollen percentage diagram

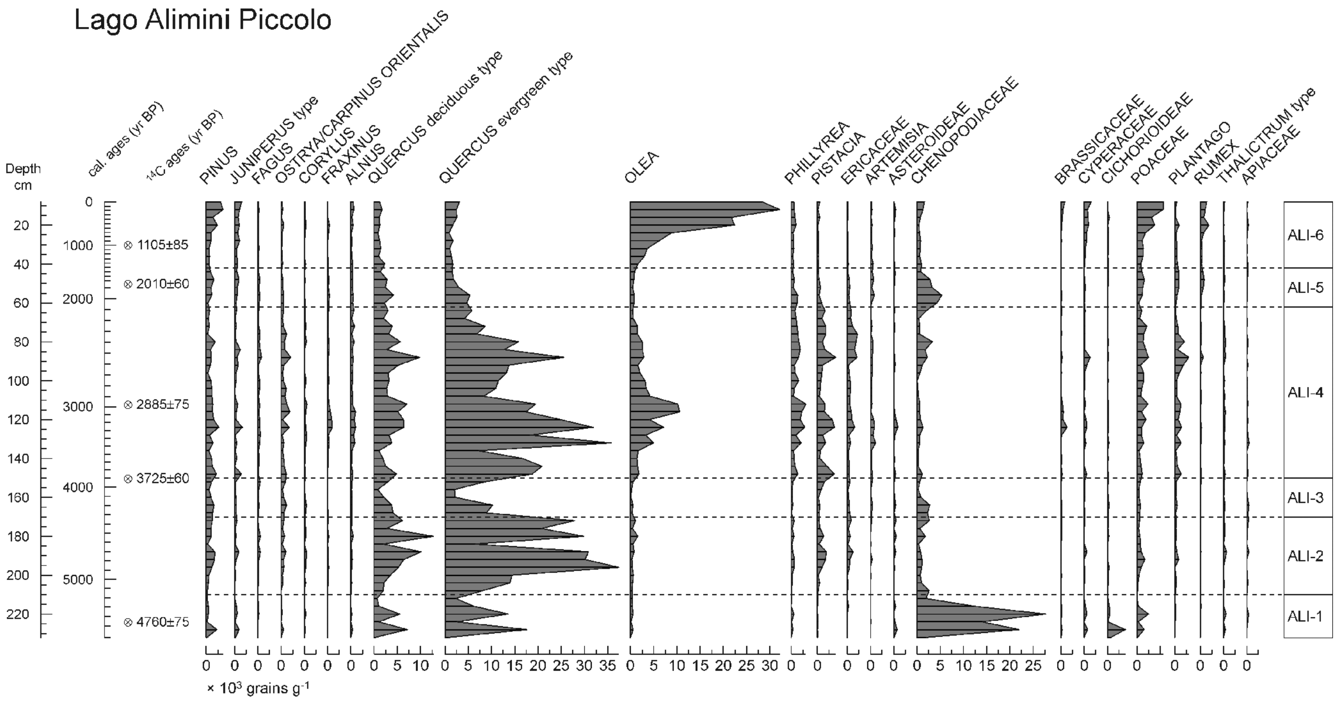

Figure 4 Lago Alimini Piccolo. Pollen concentration diagram for selected taxa

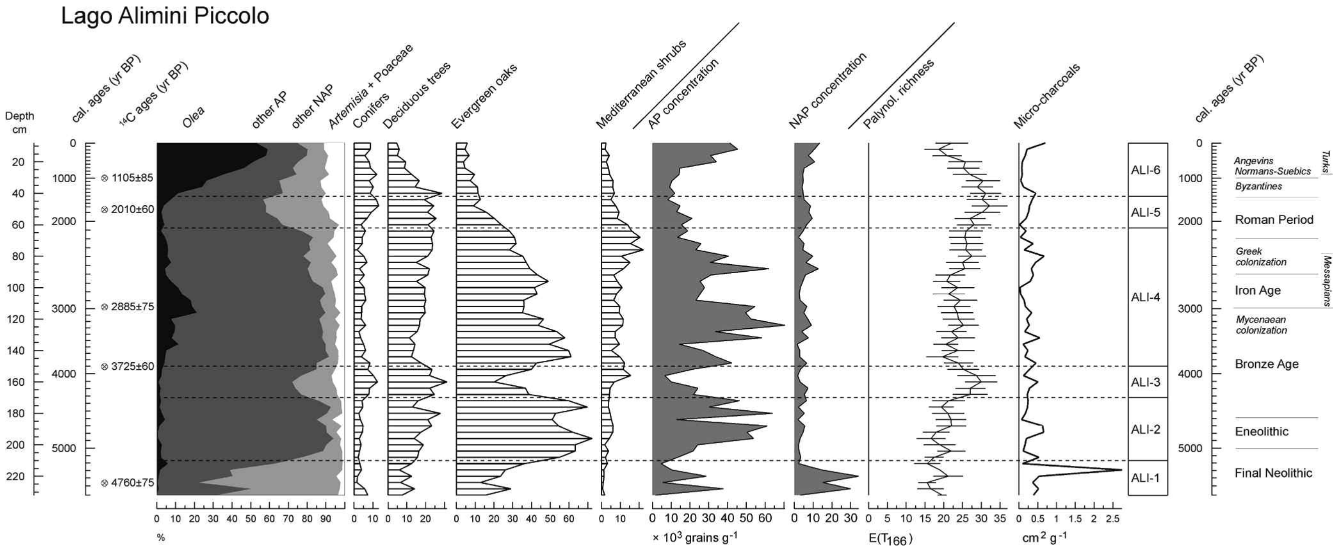

Figure 5 Lago Alimini Piccolo. Summary pollen diagram and microcharcoal record

summary diagram (Figure 5), including also the number of identified taxa and microcharcoal concentrations, deciduous trees include all the deciduous trees, Mediterranean shrubs include *Arbutus*, other Ericaceae, *Myrtus*, *Phillyrea*, *Pistacia*, and *Cistus*.

The computer program Psimpoll 4.25 (Bennett, 2005) was used to subdivide the diagrams into local pollen assemblage zones, using the binary splitting by information content method. Six local pollen zones, numbered from the base upwards and prefixed by the site abbreviation ALI, have been distinguished.

ALI-1 (232–210 cm; *c.* 5600–5200 cal. BP)

AP percentages are the lowest of the record (22–64%). Total pollen concentrations fluctuate between 4600 and 60 000 grains/g. The tree pollen component mainly consists of *Quercus* evergreen type (13–36%), deciduous *Quercus* (10%), *Pinus* (4%) and *Olea*, the latter increasing to 6% at the top of the zone. Chenopodiaceae, reaching the highest percentage values of the pollen diagram (up to 72%), is the dominant taxon, associated with high percentages of Cichorioideae (16%) and *Pseudoschizaea* (8%) at the bottom of the zone. The number of taxa is the lowest of the record. The curve of charcoal concentration shows a sharp peak at 216 cm (>2.70 cm^2/g).

ALI-2 (210–170 cm; *c.* 5200–4350 cal. BP)

An increase in *Quercus* evergreen type, reaching the highest values of the sequence (72%), and a contemporary drop in Chenopodiaceae produce a remarkable and rapid rise in AP percentages (94%). *Quercus* deciduous pollen reaches its maximum percentage value (22%) as well. Continuously low frequencies of *Pinus*, *Pistacia*, *Olea* and *Ostrya*/*Carpinus orientalis* are recorded. NAP show low percentages and floristic diversity. Total pollen concentrations are rather heterogeneous, ranging from 8000 to 65 000 grains/g and charcoal concentrations are lower than 0.70 cm^2/g.

ALI-3 (170–150 cm; *c.* 4350–3900 cal. BP)

AP percentages decrease to 72% and total pollen concentrations to 7000 grains/g. *Quercus* evergreen type undergoes a rapid drop whereas *Pistacia* (11%) and *Pinus* (9%) attain their maximum values. Deciduous trees significantly increase, especially deciduous *Quercus* (18%) and *Ostrya*/*Carpinus orientalis* (>5%). *Fagus*, *Alnus* and *Corylus* show frequencies of around 2%. Herbs are well represented by a general increase of several taxa such as Chenopodiaceae (10%), Poaceae (5%), *Plantago* (3%), and Asteroideae (2%). *Artemisia*, Cichorioideae and Apiaceae never exceed 2%. Charcoal concentrations vary from 0.12 to 0.50 cm^2/g.

ALI-4 (150–62 cm; *c.* 3900–2100 cal. BP)

The total pollen concentrations are generally lower than 60 000 grains/g. AP percentages maintain high values (78–91%). This zone records a development of Mediterranean taxa such as *Olea* (21%), Ericaceae (9%), *Pistacia* (8%) and *Phillyrea* (8%), associated with appreciable amounts of other trees, notably deciduous *Quercus* (10–15%), *Pinus* (5%), *Ostrya*/*Carpinus orientalis* (5%), *Alnus* (3%) and *Fagus* (2%). *Quercus* evergreen type always represents the dominant tree pollen type, while Chenopodiaceae, Poaceae and *Plantago* are the most important herbaceous taxa. Charcoal concentrations never exceed 0.70 cm^2/g.

ALI-5 (62–42 cm; 2100–1500 cal. BP)

A slight reduction in AP values (56–67%) is mainly produced by a steady decrease in *Quercus* evergreen type and by an abrupt drop in the other evergreen trees. This coincides with a development of the herbaceous taxa, mainly represented by Chenopodiaceae (22%), Poaceae (9%), *Plantago* (7%), *Rumex* (5%) *Artemisia* (4%) and Asteroideae (>2%). Deciduous *Quercus* (10–15%), *Pinus* (8%) and *Juniperus* type (5%) significantly contribute to the AP frequencies. Total pollen concentrations range between 12 000 and 26 000 grains/g. Charcoal concentrations vary from 0.02 to 0.36 cm^2/g.

ALI-6 (42–8 cm; after *c.* 1500 cal. BP)

A new rise of AP percentages (max. 80%) involves exclusively *Olea* (up to 59%), whereas most trees keep their declining trend. *Olea* concentrations display an exponential growth, starting in the middle of zone ALI-5. *Pinus* and *Juniperus* type curves keep stable. Grasses reach their maximum percentage value (11%) and are accompanied by appreciable frequencies of Chenopodiaceae (7%), *Rumex* (4%) and *Plantago* (4%). Cyperaceae and aquatic plants show a slight increase. Total pollen concentrations fluctuate between 12 000 and 55 000 grains/g. Charcoal concentrations increase exponentially up to 0.70 cm^2/g.

Vegetation history at Lago Alimini Piccolo

The pollen data from Lago Alimini Piccolo allow a reconstruction of the vegetation dynamics of the easternmost region of Italy, in relation to possible climate changes and human activity.

5600–5200 cal. BP

High percentages of Chenopodiaceae and Cichorioideae pollen and low palynological richness (Figure 5) are likely to result from selective preservation of pollen grains of local origin (Bottema, 1975; Havinga, 1984). Besides, a considerable amount of *Pseudoschizaea* at the base of the record suggests incidence of seasonal desiccation (Scott, 1992) and freshwater flows with erosional processes in the basin (Pantaleón-Cano *et al.*, 2003). Over-representation of pollen of local origin (Chenopodiaceae and Cichorioideae) affects the percentage representation of the regional vegetation, which mainly consisted of evergreen oaks. Deciduous oaks and a few other tree species in limited amounts characterized the deciduous component of the vegetation.

5200–4350 cal. BP

A dense arboreal vegetation dominated the landscape of the Salento Peninsula, suggesting that climate was more humid than at present. Both evergreen and deciduous oaks show exponential increases of pollen concentration, spanning approximately four centuries, from 5200 to 4800 cal. BP. A temporary moderate drop of evergreen oaks is recorded between 4800 and 4500 cal. BP. The coeval occurrence of cereals and an increase of microcharcoal may suggest human activity, although no archaeological evidence in the area confirms this hypothesis. On the whole, the landscape was covered by a dense oak-dominated Mediterranean evergreen vegetation, with a few other shrubs (eg, *Pistacia*, *Olea*, *Phillyrea* and Ericaceae). The deciduous vegetation, characterized by *Quercus*, shows an increase of floristic richness resulting from modest but continuous occurrences of several deciduous trees, such as *Ostrya*/*Carpinus orientalis*, *Alnus*, *Corylus*, *Fagus* and *Ulmus*. In the case of Lago Alimini Piccolo, which at present would, under natural conditions, be entirely surrounded by evergreen vegetation (Blasi and Michetti, 2005), the finds of pollen of mesophilous trees such as *Fagus, Betula* and *Abies*, which require temperate and humid conditions, are likely to indicate long-distance pollen transportation. These taxa now show limited distributions in southern Italy, but are abundant in the sector of the Balkan peninsula facing the Salento region, less than 100 km east of the Alimini lakes. Nevertheless, it cannot be excluded that sparse stands of mixed deciduous oak woodland might have been preserved in the most humid areas of the Salento peninsula.

4350–3900 cal. BP

A distinct opening of the forest, with a decrease of AP percentages and concentrations, reaching minimum values around 4100 cal. BP, matches a rapid change in vegetation composition and a contemporary increase in the number of taxa (Figure 5). Evergreen oaks were particularly affected by this event. Most herbaceous taxa, such as Chenopodiaceae, Poaceae, *Plantago*, *Artemisia*, Asteroideae, Cichorioideae, Apiaceae and Fabaceae, show percentage increases. At the same time, there is a moderate percentage rise of conifers and of several deciduous trees, such as *Alnus*, *Fagus*, *Corylus*, *Carpinus betulus* and *Ostrya*/*Carpinus orientalis*. However, these deciduous taxa do not show important changes in pollen concentration (Figure 4). The opening of the forest ends with a marked increase of Mediterranean shrubs. Neither reliable anthropogenic pollen markers nor increasing trends in the charcoal curve are found, which would, if present, suggest a relationship of this deforestation phase with human activity. In fact, the increase of Chenopodiaceae and *Plantago*, frequently interpreted as secondary indicators of human activity (Behre, 1990), may also reflect an increase of water salinity, since several species of these two taxa live in coastal environments. The complete absence of cereal pollen during this phase would suggest that this increase of herbs represents a temporary aridification process, rather than the result of human activity. In support of this hypothesis is the lack of human settlements of this period in the area. It is noteworthy that this event did not affect conifers and deciduous trees, which – as discussed above – were not significant components of the local vegetation, their pollen probably being of long-distance origin. This is certainly the case for *Fagus*, *Betula* and *Abies*, increasing their percentages over 1%, and for a few finds of *Picea*, presumably from the Balkan peninsula.

3900–2100 cal. BP

During this interval, the Salento landscape was characterized by rapid recovery of arboreal vegetation leading to a rich maquis vegetation dominated by evergreen oaks with other Mediterranean trees and shrubs. However, the forest cover shows a steady and moderate degradation through time, associated with an increase of herbs and Mediterranean shrubs. This process might be due to a progressive increase of human activities during the Bronze age, but also to a transition from *Quercion ilicis* to *Oleo-Ceratonion* communities that in such a climatically sensitive area could be induced by even slight precipitation or temperature changes. Around 3600 cal. BP there is a remarkable increase of *Olea*, reaching its maximum *c*. 3100 cal. BP. It is very difficult to assess whether *Olea* was cultivated in the region at that time. In fact, even though archaeological evidence documents commercial relationships with the Mycenaeans (Orlando, 1983, 1994), who most likely used to cultivate *Olea* (Jahns, 1993), the increase of evergreen shrubs such as *Pistacia*, *Phillyrea* and Ericaceae, may be consistent with a natural spread of *Oleo-Ceratonion* vegetation.

After 2600 cal. BP the area became more intensively exploited, as shown by the almost continuous presence of cereals, and by the settlements of Messapian populations first and Greek colonizers later. Archaeobotanical investigations carried out in the nearby Messapian town of Roca Vecchia reveal the presence of *Hordeum* sp. macrofossils around the eighth century BC (Harding, 1999). Human impact is likely to have played an important role in the increase of shrubs, resulting from oak forest clearance for land-use activities. Surprisingly, during this period of distinct human activity in the region, *Olea* shows a declining trend, indicating that it was not extensively cultivated, and suggesting that the expansion recorded before 3000 BP could be substantially due to naturally favourable conditions.

2100–1500 cal. BP

During the Roman occupation there is a significant opening of the forest with expansion of several herbaceous taxa, especially Chenopodiaceae, Poaceae, *Artemisia* and *Plantago*. The declining trend of evergreen forest appears to continue its progression at the same time as an intensification of human impact on the landscape. In fact, the continuous presence of Cannabaceae associated with cereals may represent agricultural activity. The cultivation of Cannabaceae for plant textiles is well documented at Lago Albano and Lago di Nemi in central Italy, where great amounts of *Cannabis* effectively prove cultivation of hemp by the Romans in the first and second centuries AD (Mercuri *et al*., 2002). The record of *Linum* is not easily correlated with its cultivation, since wild species of *Linum* occur in the area (Marchiori *et al*., 1998).

A temporary increase of Chenopodiaceae might be the vegetational response to an input of salty water from the Adriatic Sea into the lake. The increase of halophilic vegetation is supported by the record of *Limonium* type and *Ruppia*, pointing to a brackish environment. A significant development of *Plantago* might also be related to halophilic conditions. In fact, presently *Ruppia maritima* lives in the brackish water of Lago Alimini Grande (Marchiori *et al*., 1998) and several species of *Limonium* colonize its shores together with *Plantago crassifolia* and other halophytes. The interpretation of an increase of *Rumex* is difficult. It may either indicate pasture practice (Behre, 1981) around the Alimini lakes, or suggest presence of species (cf. *Rumex bucephalophorus*) living in natural vegetation communities of coastal sandy soil (Pignatti, 1982).

After 1500 cal. BP

After 1500 cal. BP human impact became the dominant factor shaping the landscape, causing a further decrease of the natural arboreal cover, with reduction or even disappearance of many tree taxa. Nevertheless, the landscape was not treeless. In fact, an exponential growth of *Olea*, starting around 1900 cal. BP, demonstrates the progressive dedication of this territory to olive cultivation, which is now the main agricultural activity in the Salento region. From 1200 cal. BP the microcharcoal record shows an exponential increase of fire frequencies parallel to *Olea*. The increase of *Olea* cultivation and incidence of fires may reflect a demographic increase and consequent need for more extensive cultivation.

The Alimini record in the context of central Mediterranean vegetation development

The pollen record from Lago Alimini Piccolo provides new information on vegetation development of the central Mediterranean during the last 5500 years. Other data on the vegetation history of the Adriatic side of Italy are available from coastal pollen sequences in the Gargano headland (Caroli and Caldara, 2007) and from the Tavoliere Plain (Caldara *et al*., 2003; Simone *et al*., 2007), more than 250 km northwest of the Alimini lakes. Information on the past vegetation in relation to human activity in Apulia is also provided by macrofossil analyses from various archaeological sites (cf. Fiorentino, 1995, 1998; Harding, 1999).

Additional information for the mid and late Holocene has been obtained from South Adriatic marine cores (Oldfield *et al.*, 2003) and coastal records from the Balkan side of the central Adriatic and Ionian Sea (Jahns and van den Bogaard, 1998; Jahns, 2005). Only a few other pollen records are available from other regions of southern Italy, including inland areas in Sicily (Sadori and Narcisi, 2001), Calabria (Schneider, 1985) and Basilicata (Watts *et al*., 1996; Allen *et al*., 2002), and a coastal site (Grüger and Thulin, 1998) and a marine core (Russo Ermolli and di Pasquale, 2002) in Campania (Figure 1).

Mid Holocene

In the central Mediterranean region south of 43°N, the mid Holocene (6000–4000 cal. BP) is characterized by widespread oak-dominated vegetation, with both deciduous and evergreen species, recorded in Italian and Balkan coastal sequences (Jahns and van den Bogaard, 1998; Jahns, 2005; Caroli and Caldara, 2007), in marine cores (Russo Ermolli and di Pasquale, 2002; Oldfield *et al*., 2003) as well as in Sicily (Sadori and Narcisi, 2001), inland peninsular Italy (eg, Lowe *et al.*, 1996; Magri, 1999; Magri and Sadori, 1999; Allen *et al*., 2002; Drescher-Schneider *et al*., 2007), Albania (Denèfle *et al*., 2000; Fouache *et al*., 2001) and northwest Greece (Willis, 1992a, b; Lawson *et al*., 2004). A slightly different picture emerges from Corsica, where *Pinus* and *Erica* are important components of the vegetation (Reille, 1984, 1992).

Compared with inland, the coastal pollen records show especially large amounts of evergreen oaks. The highest percentages of the central Mediterranean regions are found at Lago Alimini Piccolo (up to 70%), probably because the entire Salento Peninsula is included in a potential evergreen Mediterranean vegetation, while the other coastal sites, located in northern Apulia and in the Adriatic side of the Balkan Peninsula, are enclosed in more or less narrow coastal belts of Mediterranean vegetation (Figure 1). These pollen records document that in the mid Holocene regional differences in Mediterranean vegetation distribution were similar to present.

Deforestation at 4000 cal. BP

One of the prominent features of the Alimini record is the deforestation phase, mainly affecting evergreen vegetation, recorded between 4350 and 3900 cal. BP. As no evidence, either archaeological or palynological, of anthropogenic disturbance is present, one may question whether this event has a mainly climatic character

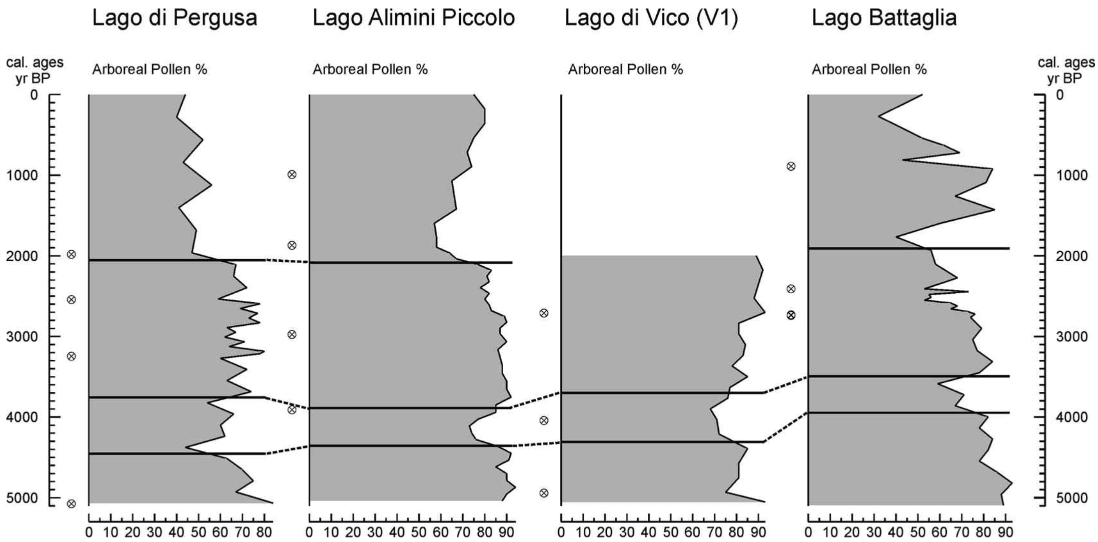

Figure 6 Comparison of landscape openness at Lago di Pergusa (calibrated and redrawn from Sadori and Narcisi, 2001), Lago Alimini Piccolo, Lago di Vico (calibrated and redrawn from Magri and Sadori, 1999) and Lago Battaglia (redrawn from Caroli and Caldara, 2007). The horizontal line marks the onset of the '4000 cal. BP' deforestation phase. Circles indicate the position of radiocarbon dates

and, more specifically, whether it is related to Mediterranean climate dynamics. In case of a climatic event, similar vegetation patterns are expected to be traced in other pollen records from the central Mediterranean region, particularly in the realm of evergreen vegetation.

At Lago di Pergusa, in central Sicily, now included in a potential mesophilous evergreen vegetation, but actually largely deforested, a clear decrease of AP concentrations and percentages, especially of evergreen oaks, is found around 4450 cal. BP (Figure 6), along with an increase in floristic richness (Sadori and Narcisi, 2001). Deciduous trees show a moderate decline and a rapid recovery, around 4100 cal. BP. Evergreen oaks together with *Olea* show a significant increase only around 3500 cal. BP.

Lago Salso, a coastal site just south of the Gargano Promontory in northern Apulia, lies in the driest area of the Italian Peninsula, with mean annual precipitation <500 mm and very sparse arboreal vegetation within the Mediterranean vegetation domain. A pollen diagram (Simone *et al*., 2007) shows a clear change of the vegetation on the Gargano Promontory from shrubby woodland to open landscape around 4000 cal. BP. After this event the pollen content of the sediment is very reduced.

Lago Battaglia is a coastal lake in an area of the Gargano Promontory potentially included in the *Quercion ilicis* alliance (Blasi and Michetti, 2005), with *Pinus halepensis* woods sometimes associated with *Quercus ilex*. The pollen concentration diagram records a collapse at 3950 cal. BP, which is 'definitive and not associated with the presence of cultivated plants or with other evidence of human activity' (Caroli and Caldara, 2007). AP percentages drop from >80% to <60% (Figure 6), with evergreen oaks decreasing from 20% to 10%, while deciduous oaks are generally stable. The forest vegetation recovers around 3500 cal. BP with a considerable expansion of *Pinus*, while evergreen oaks maintain moderate values.

The Adriatic marine record RF93-30 (Oldfield *et al.*, 2003) is located 18 km from the north coast of the Gargano Promontory, where Mediterranean vegetation is found. However, it probably includes pollen from more northern latitudes in the Adriatic region with mainly deciduous components. A clear drop of AP, affecting both deciduous and evergreen oaks, is recorded soon after a tephra ascribed to the Avellino eruption. A recent calibration of the Avellino tephra, on the basis of several lines of evidence, dates it at 4077 cal. BP (Vigliotti, 2006). The age of the recovery of forest conditions is uncertain but presumably occurred a few centuries later.

The inland site Lago Grande di Monticchio, 250 km east of Lago Alimini Piccolo, located in a deciduous vegetation domain with little evidence of Mediterranean woodland (Figure 1), has been extensively studied. The final combined Holocene pollen record, however, shows a sampling gap between 4100 and 3500 cal. BP, thus omitting evidence for a possible deforestation event (Allen *et al.*, 2002).

A clear decline of AP is recorded in pollen sequences of central Italy (Latium), located in a more temperate vegetation belt, with mainly deciduous trees but still with some Mediterranean elements. It is found around 4250 cal. BP at Lagaccione (Magri, 1999) and 4300 cal. BP at Lago di Vico (Magri and Sadori, 1999), where it is associated with evidence of agricultural activity. In both lakes, during the deforestation event, single grains of *Cedrus* pollen are recorded, most likely transported by air masses coming from Africa, where the closest forests of *Cedrus* are now found (Magri and Parra, 2002). At Lago di Vico the forest recovers around 3600 cal. BP (Figure 6), while at Lagaccione the pollen record ends before the recovery.

Northward, at Lago dell'Accesa in Tuscany (Drescher-Schneider *et al*., 2007), a slight AP percentage decrease, corresponding to a marked decline of Mediterranean trees and shrubs, is recorded between 4200 and 3600 cal. BP. The present potential vegetation of the area is transitional between the *Quercion ilicis* alliance and the mesophilous deciduous woodlands of the *Quercion pubescenti-petreae* alliance.

In Corsica, a number of pollen records have been studied (Reille, 1984, 1992; Reille *et al.*, 1999), but only few of them have a detailed chronological control. The site of Lac de Creno (Reille *et al.*, 1999), located at 1310 m in a supramediterranean vegetation belt, shows no distinct deforestation phase, while the pollen record from the coastal site Crovani (Reille, 1992) testifies a forest opening starting at 4400–4350 cal. BP.

To our knowledge, no clear temporary deforestation events around 4000 cal. BP are recorded in the western side of the Balkan Peninsula, neither in the areas with potential evergreen vegetation (Jahns and van den Bogaard, 1998; Jahns, 2005), nor inland (Willis, 1992a, b; Denèfle *et al.*, 2000; Fouache *et al.*, 2001;

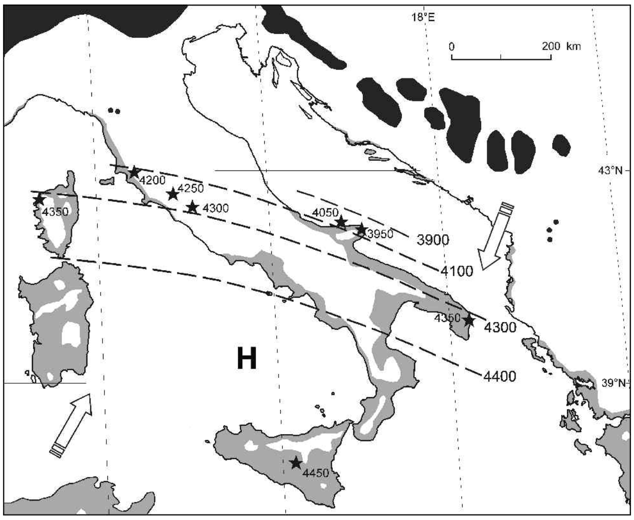

Figure 7 Tentative reconstruction of the climatic trend affecting the central Mediterranean regions around 4000 cal. BP. The age (cal. BP) of the onset of this event is indicated for the sites where deforestation is recorded. The dashed lines (isochrones, cal. BP) indicate the geographical progression of the onset of the deforestation. The light grey area represents the distribution of the potential Mediterranean sclerophyllous vegetation (modified from Bohn *et al.*, 2000). The dark grey area represents the modern distribution of *Picea abies* (modified from Skrøppa, 2003). The arrows indicate wind directions, based on the finds of extra-regional pollen grains, suggesting a clockwise rotation around a possible high-pressure cell (H)

Lawson *et al.*, 2004). Similarly, in Italy north of 43°N, where deciduous vegetation is prevalent, the 4000 cal. BP event is not recorded.

From the above data, it is clear that this deforestation phase is not restricted to Lago Alimini Piccolo: clear openings of the vegetation occurred around 4000 cal. BP at many Italian sites south of 43°N, especially in the Mediterranean vegetation belt. They are not recorded at exactly the same time everywhere. In fact, the beginning of the deforestation is recorded around 4450 cal. BP at Lago di Pergusa, 4350 cal. BP at Lago Alimini Piccolo and Crovani, 4300 cal. BP at Lago di Vico, 4250 cal. BP at Lagaccione, 4200 cal. BP at Lago dell'Accesa, 4050–3950 in the sites around the Gargano Promontory (Figures 6 and 7). Therefore, there is a 500 yr difference between the earliest and the latest record. Such a large range could be partly ascribed to dating deficiencies and calibration problems, as most of the records do not have very high resolution time control. However, the onset of the deforestation shows a clear geographic pattern, proceeding with a time-transgressive trend from southwest to northeast and involving several Italian sites located in the Mediterranean vegetation belt, both in the Tyrrhenian and in the Adriatic sides of the peninsula, as well as in Corsica and Sicily (Figure 7).

This time-transgressive trend suggests that a natural phenomenon was the main factor affecting the vegetation cover. The most important limiting factors for evergreen vegetation are cold winter temperatures and low winter precipitation. A lowering of winter temperatures would affect thermophilous vegetation first in the northern and then the southern regions. Our data record the opposite, excluding cold temperatures as a main factor. Therefore, a reduction of precipitation, producing a progressive aridification from Sicily to the central Adriatic region is a reasonable hypothesis for the observed pattern.

Aridification processes in the Mediterranean basin are mainly due to expansions of the anticyclonic belt (Piervitali *et al.*, 1997). Our data suggest a general progression of a north African high-pressure cell towards the northeast affecting the Italian territory, but not the Balkan Peninsula, since around 4450 cal. BP. This condition lasted until 3800–3600 cal. BP, depending on the sites.

Pollen may also be used as proxy for past wind directions (Magri and Parra, 2002). In our case, as anticyclonic circulation involves a clockwise rotation of air masses, we should expect to find evidence for a different wind provenance in the sites at opposite margins of the high-pressure cell. The African origin of winds reaching the western side of the Italian peninsula during aridification phases is documented by pollen of African origin at various sites of the Latium region (Magri and Parra, 2002). On the contrary, the increased finds of long distance temperate pollen (*Picea*, *Abies*, *Fagus* and *Betula*) at Lago Alimini Piccolo, indicates a prevalent northern origin of winds in the eastern side of Italy (Figure 7). We suggest that, during the 4000 cal. BP event, the southern provenance of winds in western Italy, coupled with the northern provenance of winds in eastern Italy, may reflect a general clockwise rotation of air masses around a high-pressure cell in the central Mediterranean area.

A severe drought event around 4000 cal. BP, recorded over a broad longitudinal belt from Africa to Tibet (Dalfes *et al.*, 1997; Gasse, 2000), is widely thought to have caused the collapse of civilizations in the Near and Middle East (Weiss *et al.*, 1993; Cullen *et al.*, 2000). Further investigation, with the help of palaeoclimate modellers, will verify whether the central Mediterranean event is part of a wider pattern of atmospheric circulation (eg, ITCZ latitudinal shift), through a better definition of the chronological setting, of possible transgressive trends, and of the location of the relative positions of high- and low-pressure cells system.

The late-Holocene expansion of *Olea*

In most pollen records from the Mediterranean belt in the Italian peninsula, the recovery of vegetation after the 4000 cal. BP event is characterized by an increase of evergreen vegetation. Different taxa are involved at different sites: in central Italy, in a mostly deciduous vegetation landscape (eg, Lago dell'Accesa and Lago di Vico), the most important evergreen element is *Quercus ilex*; in the northeastern slopes of the Gargano Promontory (Lago Battaglia) *Pinus halepensis* shows a remarkable development; in the Salento Peninsula (Lago Alimini Piccolo) an expansion of evergreen oaks is accompanied by other Mediterranean trees and shrubs in significant frequencies (*Olea*, *Pistacia* and *Phillyrea*); in Sicily (Lago di Pergusa) the increase of *Olea* is especially important, together with evergreen oaks. The main exception to this trend is found in the Adriatic marine core RF 93-30, where a considerable proportion of pollen of deciduous trees was probably transported from outside the Mediterranean vegetation belt.

A general late-Holocene increase of evergreen vegetation has been largely recognized in the Mediterranean basin, and ascribed to either human activity (Reille and Pons, 1992; Pons and Quézel, 1998) or climatic trends (Jalut *et al.*, 2000 and references therein). In this respect, the expansion of *Olea* represents a fundamental question, as *Olea* is both an emblematic tree of the Mediterranean natural environment and a species of great economic importance.

At Lago di Pergusa, in Sicily, *Olea*, already present at the beginning of the Holocene, increased around 8000 cal. BP, reaching its maximum values (almost 20%) between 3500 and 2500 cal. BP (Sadori and Narcisi, 2001). In the other Italian and Balkan sites located in the evergreen vegetation belt (eg, Lago Battaglia, Lago dell'Accesa, Lake Voulkaria and Malo Jezero) *Olea* percentages never exceed 10%, even in historical times, while in coastal sites in Corsica (Reille, 1992) a value of 10% is only occasionally surpassed.

At Lago Alimini Piccolo, *Olea* progressively increased, together with natural partners of the maquis (eg, *Phillyrea* and *Pistacia*), soon after the 4000 cal. BP deforestation phase, when anthropogenic indicators were sparse, reaching a first maximum around 3100 cal. BP, at a time of connections between the local settlements and the Mycenaean civilization, suggesting a possible human-driven process. In the coeval Bronze Age settlement of Monopoli – Piazza Palmieri (Fiorentino, 1995), located on the Apulian coast 130 km northwest of Lago Alimini Piccolo, a large number of *Olea* macroremains (charcoal and stones) confirm that olive trees were abundant in the thermophilous vegetation belt along the southern Adriatic coast and locally used by human populations.

A morphobiometrical study on olive stones in the western Mediterranean Basin has shown that during the Bronze Age there is evidence for selective exploitation and management of wild olive trees for fruit production (Terral *et al.* 2004), not implying planting by humans. Such primitive management might have further increased pollen production and *Olea* representation in pollen diagrams. However, human exploitation of olive trees does not easily explain the general increase of wild Mediterranean shrubs.

Both at Lago di Pergusa and at Lago Alimini Piccolo, as well as at Lago d'Averno near Naples (Grüger and Thulin, 1998) the Roman occupation coincided with a modest diffusion of *Olea*, although selection, cultivation and trade by the Romans are well documented by numerous historical sources. This paradox suggests that between approximately 2500 and 1500 cal. BP climate conditions were not especially favourable for olive cultivation in southern Italy, in contrast with the Bronze Age situation, when even primitive agricultural practices may have benefited from plentiful wild olive productions.

The extraordinary recent expansion of *Olea* since the sixth century AD (up to 60%) only partially matches the Lago di Pergusa record (max. 10%). In the Salento Peninsula the Byzantines (AD 554–1068, Arthur, 1997) developed intensive cultivation of olive trees, never recorded in such numbers in any other site in the central Mediterranean.

Conclusions

The pollen record of Lago Alimini Piccolo represents a particularly complex environment, where vicinity of the sea, climatic changes and human occupations have a combined role in shaping the vegetational landscape.

Some vegetation changes recognized in the pollen diagram represent local influences. They are either ascribed to sedimentary factors, for example the high proportions of Chenopods, Cichorioideae and *Pseudoschizaea* at the bottom of the record, or to human impact, for example the increase of *Olea* during the Byzantine times.

In many cases it is difficult to decipher whether the observed vegetational changes are due to natural trends or human activity. The opening of the forest recorded around 2100 cal. BP may be reasonably ascribed to the Roman occupation. However, in spite of cultivation witnessed by documentary sources, the unexpectedly low frequencies of *Olea*, recorded both at Lago Alimini Piccolo and at other central Mediterranean sites, suggests that climate conditions may have been unfavourable for the development Mediterranean vegetation.

In some cases, it has been possible to disentangle human and natural factors: the deforestation event between 4350 and 3900 cal. BP fits a general aridification pattern involving the Mediterranean vegetation belt in Sicily and southern-central Italy. This follows a time-transgressive trend from southwest to northeast, suggesting that it was a natural phenomenon, possibly linked to a temporary expansion or northward displacement of the African high-pressure cell.

A clearly human-induced vegetation change is documented by the exponential increase of *Olea* from Byzantine (sixth century) to modern times, which does not match any other pollen record in the central Mediterranean. Even at present, the Salento peninsula is especially devoted to olive cultivation.

In some other situations, it appears that human activity and climate conditions concur in determining vegetational dynamics. In fact, abundant olive pollen and macrofossils in Bronze Age layers show that *Olea* was used by the Apulian populations, exploiting and probably managing natural olive stands widely distributed along the coast. At the same time, the expansion of *Olea* around 3000 cal. BP, paralleling analogous vegetation trends in Sicily, is accompanied by an increase of evergreen taxa, pointing to an enhancement of Mediterranean conditions in climate.

The Lago Alimini Piccolo record, located in a bioclimatically transitional area, provides evidence of alternate transitions from oak-dominated woods (*Quercion ilicis* belt) and more thermophilous maquis (*Oleo-Ceratonion* belt), in response to even minor climate changes and/or human induced degradation processes.

The peculiar location of Lago Alimini Piccolo, in a typical Mediterranean domain rather distant from the deciduous vegetation belt, hints at the source area for a number of pollen types. In particular, occurrences of *Fagus*, *Betula*, *Abies* and *Picea*, most likely of Balkan origin, are particularly useful to outline the atmospheric circulation during the 4000 cal. BP aridification event.

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References

Arthur, P. 1997: Tra Giustiniano e Roberto il Guiscardo. Approcci all'archeologia del Salento in età bizantina. In Gelichi S., editor, *I Congresso Nazionale di Archeologia Medievale*. Edizioni all'Insegna del Giglio, 194–99.

Allen, J.R.M., Watts, W.A., McGee, E. and **Huntley, B.** 2002: Holocene environmental variability – the record from Lago Grande di Monticchio, Italy. *Quaternary International* 88, 69–89.

Behre, K.-E. 1981: The interpretation of anthropogenic indicators in pollen diagrams. *Pollen et Spores* 23, 225–45.

—— 1990: Some reflections on anthropogenic indicators and the record of prehistoric occupation phases in pollen diagrams from the Near East. In Bottema, S., Entjes Nieborg, G. and van Zeist, W., editors, *Man's role in the shaping of the eastern Mediterranean landscape*. Balkema, 219–30.

Bennett, K.D. 2005: *Documentation for psimpoll 4.25 and pscomb 1.03: C programs for plotting pollen diagrams and analysing pollen data*. Retrieved from http://chrono.qub.ac.uk/psimpoll/psimpoll.html

Besnard, G., Rubio de Casas, R. and **Vargas, P.** 2007: Plastid and nuclear DNA polymorphism reveals historical processes of isolation and reticulation in the olive tree complex (*Olea europaea*). *Journal of Biogeography* 34, 736–52.

Blasi, C. and **Michetti, L.** 2005: Biodiversità e clima. In Blasi, C., Boitani, L., La Posta, S., Manes, F. and Marchetti, M., editors, *Stato della Biodiversità in Italia*. Palombi Editori, 57–66.

Bohn, U., Gollub, G. and **Hettwer, C.** 2000: *Map of the natural vegetation of Europe*. Federal Agency for Nature Conservation.

Bottema, S. 1975: The interpretation of pollen spectra from prehistoric settlements (with special attention to Liguliflorae). *Palaeohistoria* 17, 17–35.

Bottema, S. and **Sarpaki, A.** 2003: Environmental change in Crete: a 9000-year record of Holocene vegetation history and the effect of the Santorini eruption. *The Holocene* 13, 733–49.

Caldara, M., Cazzella, A., Fiorentino, G., Lopez, R., Magri, D., Moscoloni, M., Narcisi, B. and **Simone, O.** 2003: The relationship between the Coppa Nevigata settlement and the wetland area during the Bronze Age (South eastern Italy). In Fouache, E., editor, *The Mediterranean world environment and history*. Elsevier, 429–37.

Caroli, I. and **Caldara, M.** 2007: Vegetation history of Lago Battaglia (eastern Gargano coast, Apulia, Italy) during the middle-late Holocene. *Vegetation History and Archaeobotany* 16, 317–27.

Carrión, J.S., Yll, E.I., Willis, K.J. and **Sánchez, P.** 2004: Holocene forest history of the eastern plateaux in the Segura Mountains (Murcia, southeastern Spain). *Review of Palaeobotany and Palynology* 132, 219–36.

Cattaneo, A., Correggiari, A., Langone, L. and **Trincardi, F.** 2003: The late-Holocene Gargano subaqueous delta, Adriatic shelf: sediment pathways and supply fluctuations. *Marine Geology* 193, 61–91.

Ciaranfi, N., Pieri, P. and **Richetti, G.** 1988: Note alla carta geologica delle Murge e del Salento (Puglia centromeridionale). *Memorie Società Geologica Italiana* 41, 449–60.

Clark, R.L. 1982: Point count estimation of charcoal in pollen preparations and thin sections of sediments. *Pollen et Spores* 24, 523–35.

Cullen, H.M., deMenocal, P.B., Hemming, S., Hemming, G., Brown, F.H., Guilderson, T. and **Sirocko, F.** 2000: Climate change and the collapse of the Akkadian empire: evidence from the deep sea. *Geology* 28, 379–82.

Curti, L. and **Lorenzoni, G.G.** 1969: Ricerche sulla vegetazione dell'Isola Grande (Porto Cesareo – Lecce). *Atti e Relazioni Accademia Pugliese delle Scienze* 26, 3–42.

Curti, L., Lorenzoni, G.G. and **Marchiori, S.** 1976: Macchia degradata e gariga a *Thymus capitatus* (L.) Hoffmgg. et Link del Salento (Puglia meridionale – Italia). *Notiziario Fitosociologico* 12, 31–48.

Dalfes, H.N., Kukla, G. and **Weiss, H.** 1997: *Third millennium BC climate change and old world collapse*. Springer-Verlag.

De Marco, A., Gentile, A. and **Nuovo, G.** 1983: Aspetti dinamici e composizionali degli apporti attuali nel Lago Alimini Piccolo presso Otranto (Puglia). *Bollettino Società Geologica Italiana* 102, 407–17.

Denèfle, M., Lèzine, A.-M., Fouache, E. and **Dufaure, J.-J.** 2000: A 12,000-year pollen record from Lake Maliq, Albania. *Quaternary Research* 54, 423–32.

Drescher-Schneider, R., de Beaulieu, J.-L., Magny, M., Walter-Simonnet, A.-V., Bossuet, G., Millet, L., Brugiapaglia, E. and **Drescher, A.** 2007: Vegetation history, climate and human impact over the last 15,000 years at Lago dell'Accesa (Tuscany, Central Italy). *Vegetation History and Archaeobotany* 16, 279–99.

Eastwood, W.J., Leng, M.J., Roberts, N. and **Davis, B.** 2007: Holocene climate change in the eastern Mediterranean region: a comparison of stable isotope and pollen data from Lake Gölhisar, southwest Turkey. *Journal of Quaternary Science* 22, 327–41.

Fiorentino, G. 1995: Primi dati archeobotanici dell'insediamento dell'età del Bronzo di Monopoli – Piazza Palmieri. *Taras* 15, 335–73.

—— 1998: L'exploitation du milieu par l'Homme du Paléolithique à l'âge du Bronze en Italie sud-orientale (Pouilles): données anthracologiques et carpologiques. PhD Thesis, University Montpellier II.

Fouache, E., Dufaure, J.-J., Denèfle, M., Lézine, A.-M., Léra, P., Prendi, F. and **Touchais, G.** 2001: Man and environment around lake Maliq (southern Albania) during the Late Holocene. *Vegetation History and Archaeobotany* 10, 79–86.

Gasse, F. 2000: Hydrological changes in the African tropics since the Last Glacial Maximum. *Quaternary Science Reviews* 19, 189–211.

Grüger, E. and **Thulin, B.** 1998: First results of biostratigraphical investigations of Lago d'Averno near Naples relating to the period 800 BC-800 AD. *Quaternary International* 47/48, 35–40.

Guerricchio, A. and **Zezza, F.** 1982: Esempio di Mapping da foto aeree e da immagini da satellite in zone carsiche: la Penisola Salentina. *Geologia Applicata e Idrogeologia* 17, 507–26.

Harding, J.L. 1999: *Environmental change during the Holocene in south-east Italy: an integrated geomorphological and palynological investigation*. Larix Books.

Havinga, A.J. 1984: A 20-year experimental investigation into the differential corrosion susceptibility of pollen and spores in various soil types. *Pollen et Spores* 26, 541–58.

Hughen, K.A., Baillie, M.G.L., Bard, E., Beck, J.W., Bertrand, C.J.H., Blackwell, P.G., Buck, C.E., Burr, G.S., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Kromer, B., McCormac, G., Manning, S., Reimer, R.W., Remmele, S., Southon, J.R., Stuvier, M., Talamo, S., Taylor, F.W., van der Plicht, J. and **Weyhenmeyer, C.E.** 2004: Marine04 marine radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* 46, 1059–86.

Jahns, S. 1993: On the Holocene vegetation history of the Argive Plain (Peloponnese, southern Greece). *Vegetation History and Archaeobotany* 2, 187–203.

—— 2005: The Holocene history of vegetation and settlement at the coastal site of Lake Voulkaria in Acarnania, western Greece. *Vegetation History and Archaeobotany* 14, 55–66.

Jahns, S. and **van den Bogaard, C.** 1998: New palynological and tephrostratigraphical investigations of two salt lagoons on the island of Mljet, south Dalmatia, Croatia. *Vegetation History and Archaeobotany* 7, 219–34.

Jalut, G., Amat, A.E., Bonnet, L., Gauquelin, T. and **Fontugne, M.** 2000: Holocene climatic changes in the Western Mediterranean, from south-east France to south-east Spain. *Palaeogeography, Palaeoclimatology, Palaeoecology* 160, 255–90.

Lawson, I., Frogley, M., Bryant, C., Preece, R. and **Tzedakis, P.** 2004: The Lateglacial and Holocene environmental history of the Ioannina basin, north-west Greece. *Quaternary Science Reviews* 23, 1599–625.

Lorenzoni, G.G. and **Ghirelli, L.** 1988: Lineamenti della vegetazione del Salento (Puglia meridionale – Italia). *Thalassia Salentina* 18, 11–19.

Lowe, J., Accorsi, C.A., Bandini-Mazzanti, M., Bishop, A., van der Kaars, S., Forlani, L., Mercuri, A.M., Rivalenti, C., Torri, P. and **Watson, C.** 1996: Pollen stratigraphy of sediment sequences from lakes Albano and Nemi (near Rome) and from the central Adriatic, spanning the interval from oxygen isotope stage 2 to the present day. *Memorie dell'Istituto Italiano di Idrobiologia* 55, 71–98.

Macchia, F. 1973: I laghi Alimini-Fontanelle: lembi di macchia mediterranea da salvare. *Atti del II Simposio Nazionale sulla conservazione della natura*. Cacucci Editore, 449–73.

Magri, D. 1999: Late-Quaternary vegetation history at Lagaccione near Lago di Bolsena (central Italy). *Review of Palaeobotany and Palynology* 106, 171–208.

Magri, D. and **Parra, I.** 2002: Late Quaternary western Mediterranean pollen records and African winds. *Earth and Planetary Science Letters* 200, 401–408.

Magri, D. and **Sadori, L.** 1999: Late Pleistocene and Holocene pollen stratigraphy at Lago di Vico (central Italy). *Vegetation History and Archaeobotany* 8, 247–60.

Marchiori, S., Medagli, P. and **Ruggiero, L.** 1998: *Guida botanica del Salento*. Congedo Editore.

Maselli, F. 2004: Monitoring forest conditions in a protected Mediterranean coastal area by the analysis of multiyear NDVI data. *Remote Sensing of Environment* 89, 423–33.

Mastronuzzi, G., Palmentola, G. and **Sansò, P.** 1994: Le tracce di alcune variazioni del livello del mare olocenico tra Torre dell'Orso e Otranto (Lecce). *Geografia Fisica e Dinamica Quaternaria* 17, 55–60.

Mastronuzzi, G., Quinif, Y., Sansò, P. and **Selleri, G.** 2007: Middle-Late Pleistocene polycyclic evolution of a stable coastal area (southern Apulia, Italy). *Geomorphology* 86, 393–408.

Mercuri, A.M., Accorsi, C.A. and **Bandini Mazzanti, M.** 2002: The long history of *Cannabis* and its cultivation by the Romans in central Italy, shown by pollen records from Lago Albano and Lago di Nemi. *Vegetation History and Archaeobotany* 11, 263–76.

Milliken, S. and **Skeates, R.** 1989: The Alimini Survey: the Mesolithic–Neolithic transition in the Salento Peninsula (S.E. Italy). *Institute of Archaeology Bulletin* 26, 77–98.

Ministero dei Lavori Pubblici 1959: *Carta della precipitazione media annua in Italia per il trentennio 1921–1950*. Servizio idrografico 24.

Oldfield, F., Asioli, A., Accorsi, C.A., Mercuri, A.M., Juggins, S., Langone, L., Rolph, T., Trincardi, F., Wolff, G., Gibbs, Z., Vigliotti, L., Frignani, M., van der Post, K. and **Branch, N.** 2003: A high resolution late Holocene palaeoenvironmental record from the central Adriatic Sea. *Quaternary Science Reviews* 22, 319–42.

Orlando, M.A. 1983: L'etá del Bronzo recente e finale ad Otranto. *Studi di Antichità* 4, 67–118.

—— 1994: Otranto. I livelli dell'età del Bronzo finale del cantiere Mitello. *Studi di Antichità* 7, 209–34.

Pantaleón-Cano, J., Yll, E.I., Pérez-Obiol, R. and **Roure, J.M.** 2003: Palynological evidence for vegetational history in semi-arid areas of the western Mediterranean (Almería, Spain). *The Holocene* 13, 109–19.

Piccinno, A. and **Piccinno, F.** 1978: Otranto, Laghi Alimini – Stazioni preistoriche. In Uggeri, G., editor, *Notiziario topografico pugliese* 1, 122–32. Museo Archeologico Provinciale "F. Ribezzo", Brindisi.

Piervitali, E., Colacino, M. and **Conte, M.** 1997: Signals of climatic change in the central-western Mediterranean Basin. *Theoretical and Applied Climatology* 58, 211–19.

Pignatti, S. 1982: *Flora d'Italia*. Edagricole.

Pons, A. and **Quézel, P.** 1998: A propos de la mise en place du climat méditerranéen. *Comptes rendus de l'Académie des sciences Paris* 327, 755–60.

Reille, M. 1984: Origine de la végétation actuelle de la Corse Sud-Orientale; analyse pollinique de cinq marais cotiers. *Pollen et Spores* 26, 43–60.

—— 1992: New pollen-analytical researches in Corsica: the problem of *Quercus ilex* L. and *Erica arborea* L., the origin of *Pinus halepensis* Miller forests. *New Phytologist* 122, 359–78.

Reille, M. and **Pons, A.** 1992: The ecological significance of sclerophyllous oak forests in the western part of the Mediterranean basin: a note on pollen analytical data. *Vegetatio* 99/100, 13–17.

Reille, M., Gamisans, J., Andrieu-Ponel, V. and **de Beaulieu, J.-L.** 1999: The Holocene at Lac Creno, Corsica, France: a key site for the whole island. *New Phytologist* 141, 291–307.

Reimer, P., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C.J.H., Blackwell, P.G., Buck, C.E., Burr, G.S., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Hogg, A.G., Hughen, K.A., Kromer, B., McCormac, F.G., Manning, S. Ramsey, C.B., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J. and **Weyhenmeyer, C.E.** 2004: IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* 46, 1029–58.

Russo Ermolli, E. and **di Pasquale, G.** 2002: Vegetation dynamics of south-western Italy in the last 28 kyr inferred from pollen analysis of a Tyrrhenian Sea core. *Vegetation History and Archaeobotany* 11, 211–19.

Sadori, L. and **Narcisi, B.** 2001: The postglacial record of environmental history from Lago di Pergusa (Sicily). *The Holocene* 11, 655–71.

Schneider, R. 1985: Analyse palynologique dans l'Aspromonte en Calabre (Italie meridionale). *Cahiers ligures de préhistoire et de protohistoire* 2, 279–88.

Scott, L. 1992: Environmental implications and origin of microscopic *Pseudoschizaea* Thiergart and Frantz ex R. Potonie´ emend. in sediments. *Journal of Biogeography* 19, 349–54.

Simone, O., Di Rita, F., Caldara, M., Magri, D. and **Gehrels, W.R.** 2007: Holocene environmental changes in the Lago Salso area (Tavoliere Plain – Southern Italy). *Quaternary International* 167/168 suppl., 386.

Skrøppa, T. 2003: *EUFORGEN technical guidelines for genetic conservation and use for Norway spruce (*Picea abies*)*. International Plant Genetic Resources Institute.

Stuiver, M. and **Reimer, P.J.** 1993: Extended ^{14}C database and revised CALIB radiocarbon calibration program. *Radiocarbon* 35, 215–30.

Terral, J.-F., Alonso, N., Buxó i Capdevila, R., Chatti, N., Fabre, L., Fiorentino, G., Marinval, P., Pérez Jordá, G., Pradat, B., Rovira, N. and **Alibert, P.** 2004: Historical biogeography of olive domestication (*Olea europaea* L.) as revealed by geometrical morphometry applied to biological and archaeological material. *Journal of Biogeography* 31, 63–77.

van Benthem, F., Clarke, G.C.S. and **Punt, W.** 1984: Fagaceae. In Punt, W. and Clarke, G.C.S., editors, *The northwest European pollen flora, IV*. Elsevier, 87–110.

Vigliotti, L. 2006: Secular variation record of the Earth's magnetic field in Italy during the Holocene: constraints for the construction of a master curve. *Geophysical Journal International* 165, 414–29.

Watts, W.A., Allen, J.R.M., Huntley, B. and **Fritz, S.C.** 1996: Vegetation history and climate of the last 15,000 years at Laghi di Monticchio, Southern Italy. *Quaternary Science Reviews* 15, 113–32.

Weiss, H., Courty, M.-A.,Wetterstrom,W., Guichard, F., Senior, L., Meadow, R. and **Curnow, A.** 1993: The genesis and collapse of third millenium north Mesopotamian civilization. *Science* 261, 995–1003.

Willis, K.J. 1992a: The late Quaternary vegetational history of northwest Greece. I. Lake Gramousti. *New Phytologist* 121, 101–17.

—— 1992b: The late Quaternary vegetational history of northwest Greece. II. Rezina marsh. *New Phytologist* 121, 119–38.

Yll, E.I., Pérez-Obiol, R., Pantaleón-Cano, J. and **Roure, J.M.** 1997: Palynological evidence for climatic change and human activity during the Holocene on Minorca (Balearic Islands). *Quaternary Research* 48, 339–47.