Research paper

The Holocene
2014, Vol. 24(11) 1491–1502

DOI: 10.1177/0959683614544063
hol.sagepub.com
SAGE

Human-derived landscape changes on the northern Etruria coast (western Italy) between Roman times and the late Middle Ages

Gaetano Di Pasquale, Mauro Paolo Buonincontri, Emilia Allevato and Antonio Saracino

Abstract

Anthracological analysis has been carried out in three sites located on the Tyrrhenian coast of central Italy (ancient northern Etruria: the castle of Donoratico, the town of Populonia and the port of Alberese), spanning between the Roman Republican Period and the Late Middle Ages (3rd century BC–13th century AD). The integrated comparison of three different local charcoal data with the regional pollen and microcharcoal data available from northern Etruria showed well that vegetation changes are completely independent of climate and strictly connected to economic and social dynamics characterising the history of this part of central Italy. Indeed, *Quercus ilex* forests progressively retracted from the 3rd century BC in favour of open macchia formations just during the growing human impact of the Romanisation when intensive agriculture and livestock grazing characterised the economic system. The transition from macchia to deciduous *Quercus* forest at the end of the Roman Period from the mid-4th to the mid-5th centuries AD and long lasting until the 9th–10th centuries AD was related to economic and cultural factors which led to a phase of land abandonment. Finally, between the 11th and 13th centuries AD, the vegetation cover shifted again towards an open macchia environment at the same time of a re-settlement phase well evidenced also by intensive orcharding. Charcoal data also showed that the expansion of olive and chestnut in central Italy only began in the Late Medieval Period (11th century AD) and not in the Roman Period. This means that extensive cultivation of chestnut and olive has very recent origins and should be attributed to one and the same macro-factor such as the set-up of the economic establishment of the feudal system and the later political organism of the Medieval town.

Keywords

Castanea sativa, Charcoal analysis, deciduous versus evergreen vegetation, late Holocene, macchia, *Olea europaea*

Received 1 April 2014; revised manuscript accepted 1 June 2014

Introduction

The Mediterranean is a complicated mosaic in which the evolution and dynamics of the natural environment were first profoundly affected by the climatic events of the early Holocene (Magny et al., 2013; Zanchetta et al., 2011, 2013) and then, from 5000 BP onwards, also by human activity (Horden and Purcell, 2000; Hughes, 2005; Roberts et al., 2011; Sadori et al., 2011; Vannière et al., 2011). In particular, the last 3000 years are considered the period most subject to human impact, especially following the spread of Roman economy (Erdkamp, 2005; Hughes, 2005; Hughes and Thirgood, 1982; Mercuri and Sadori, 2014).

While human impact on the natural environment is undeniable, the issue is at what point this impact became detectable and what form it took (Roberts et al., 2011). Recently, Harris (2013) gathered in a volume contributions of a varied nature based on palaeoecology, history and mathematical models in order to investigate the impact of human activity upon the natural environment and shed light on environmental questions of land use and deforestation during the Roman Period. The experiment revealed differences in purpose and method, but basically left '… new possibilities for profoundly deepening, and perhaps even transforming, our understanding' (Wilson, 2013).

The pollen data on their own, especially for the last 2500 years, are insufficient to interpret the changes in plant cover as the effect of climate or of man (e.g. Di Pasquale et al., 2014; Finsinger et al., 2010; Peyron et al., 2013; Sadori et al., 2004; Zanchetta et al., 2013). Charcoal analysis from archaeological contexts is a good tool to reconstruct vegetation changes mainly linked to human activity (Asouti and Austin, 2005; Chabal, 1994, 1997; Di Pasquale et al., 2014). In this respect, a multiproxy approach which considers together with charcoal and pollen also proxies unambiguously attributed to climatic forcing, such as oxygen and carbon isotopes content in fossil remains (e.g. Colonese et al., 2007; Masi et al., 2013), lake levels and glacial records (e.g. Magny et al., 2013; Zanchetta et al., 2012), geoarchaeological and pedological data (Allevato et al., 2012b; Pelle et al., 2013a,

University of Naples Federico II, Italy

Corresponding author:
Mauro Paolo Buonincontri, Department of Agriculture, University of Naples Federico II, via Università 100, I-80055 Portici, Naples, Italy.
Email: mauropaolo.buonincontri@unina.it

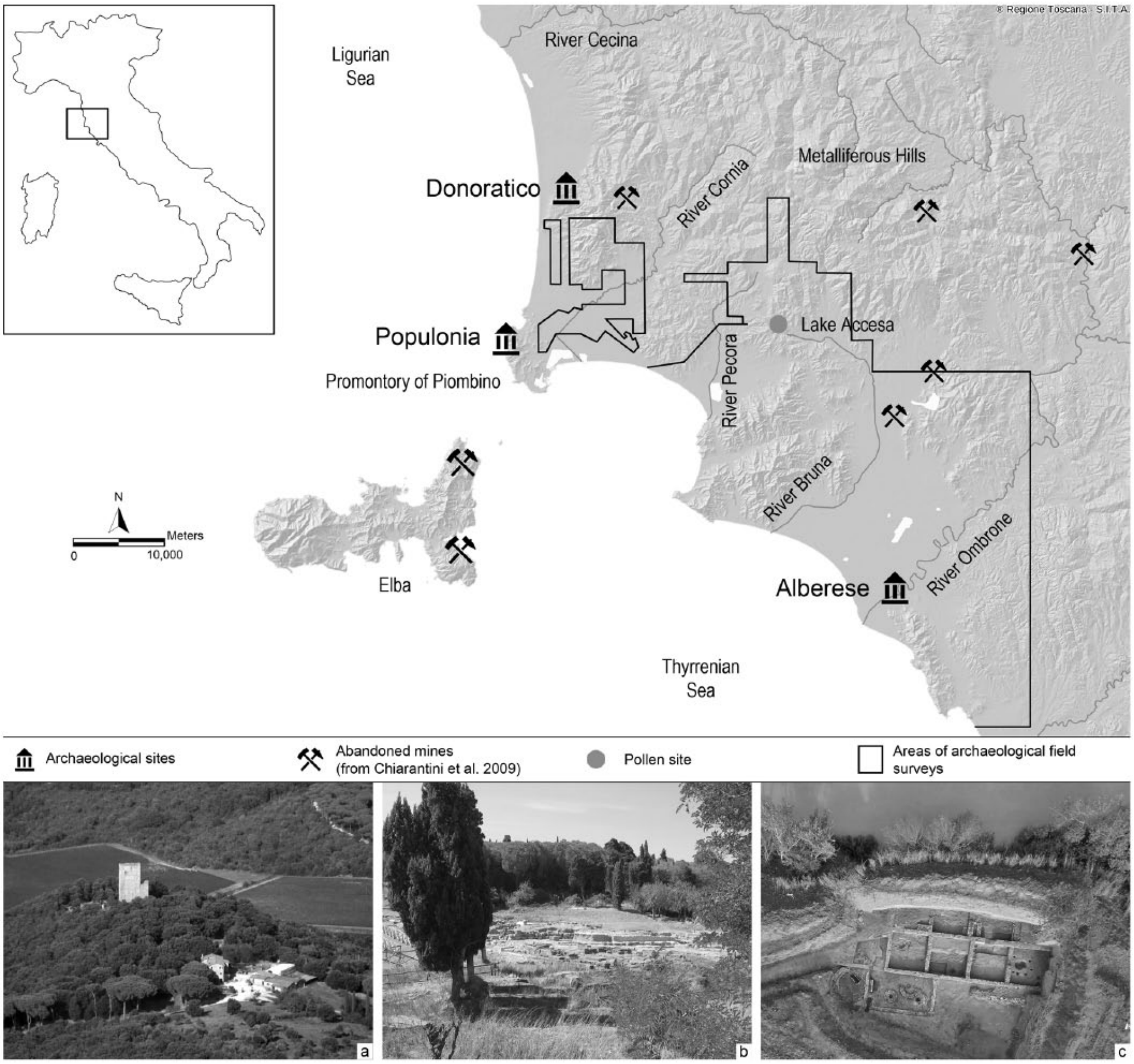

Figure 1. Study area in the Tyrrhenian central Italy: (a) aerial view of the Medieval castle of Donoratico, (b) the archaeological area of Roman Populonia and (c) aerial view of the Late Roman port of Alberese.

2013b), can be a powerful method for better interpretation of cause–effect processes.

In this study, our charcoal analysis focuses on the vegetation changes for a period between 2250 cal. yr BP (early 3rd century BC) and 650 cal. yr BP (end 13th century AD) in three archaeological sites of northern Etruria (central Italy) on the Tyrrhenian coast between the lower valley of the River Cecina and the mouth of the River Ombrone. Holocene pollen data for this area show that forest cover was characterised by alternating dominance of deciduous and evergreen oaks caused by climatic changes at Accesa Lake (Drescher-Schneider et al., 2007; Magny et al., 2007). Human impact started *c.* 8000 cal. yr. BP and greatly increased at *c.* 4300 cal. yr BP. Subsequently, although the last 2500 years are not discussed in depth, the decline of deciduous oak forest and the spread of evergreen vegetation is evident at Accesa Lake (Drescher-Schneider et al., 2007) and at Ombrone alluvial plain too (Biserni and Van Geel, 2005).

In this study, we want to prove the synergic effect of the multiproxy and multisite approach in understanding the evolution of the plant landscape between the beginning of Roman civilisation and the Late Middle Ages.

The precise objectives were as follows:

- To reconstruct the changes in the forest and agricultural landscape as regards tree species;
- To characterise human activity in terms of the chief production activity which has led to changes in the vegetation cover, using a rigorous comparison with the archaeological evidence, hence with a detailed chronological reconstruction;
- To gain new insights into the history of some of the most important arboreal landscapes in the Mediterranean, such as those with olive and chestnut.

Study area

The study area consists of the stretch of the alluvial plain between the Ligurian Sea and the south-western area of the so-called Metalliferous Hills (*Colline Metallifere*), including the Cecina Valley, the promontory of Piombino and the Ombrone valley (Figure 1). Three archaeological sites were chosen for sampling for anthracological analysis (Figure 1): the hilltop settlement of Donoratico (2nd, 3rd and 10th centuries AD; 166 m a.s.l.), the town of Populonia (between the 3rd and 1st centuries BC and between the 11th and 13th centuries AD; 164 m a.s.l.) and the river site of Alberese (between the 4th and mid-5th centuries AD; 4 m a.s.l.).

The area has a Mediterranean climate; data from the weather stations (Donoratico, Venturina and Alberese) closest to the archaeological sites show that the minimum average temperatures of the coldest month (February) are between 2.9°C and 3.3°C, and

Table 1. Chronological sequence of the sampled layers at each of the archaeological sites examined. Labelling of the layer follows archaeological documentation. For each level, the type of archaeological context and number of charcoals studied are shown.

Time interval (cal. yr BC/AD)		Archaeological sites	Sampled layers (A = activities; SU = stratigraphical unit)	Archaeological context	Charcoal
1200–1300	AD	Populonia	A 71, A 314, A 426, A515	Inhabited layer	51
1000–1200		Populonia	A 511, A 512, A 513, A 514	Inhabitation of a structure	248
900–1000		Donoratico	SU 7468, SU 7500, SU 10784	Floor of the hut	386
Hiatus					
300–450		Alberese	SU 118, SU 177, SU 157, SU 109	Metal workshop	328
100–300		Donoratico	SU 10091	Inhabited layer	529
Hiatus					
50–0	BC	Populonia	A 84	Re-habitation of Room D3	195
100–50		Populonia	SU 12285, SU 12286, SU 12287, SU 12289	Abandonment of the cistern	150
100–50		Populonia	A 81, A 86	Abandonment of Rooms D2 and D3	26
150–100		Populonia	A 79	Inhabitation of Rooms D3 and D4	51
200–150		Populonia	A 900	Building of Temple C	155
300–200		Populonia	A 326, A 504, A 504	Building of the cistern	258
300–200		Populonia	A 502	Inhabitation of Room A1	79

annual precipitation is between 700 and 800 mm. The present-day vegetation consists of stone pine woods (*Pinus pinea* L.) planted along the coast, while inland, arable crops are present on deep soils in the alluvial plain. The vegetation on the hills consists of evergreen sclerophyllous forest dominated by *Quercus ilex* L., with *Arbutus unedo* L., *Viburnum tinus* L. and *Phillyrea latifolia* L. Small stands with deciduous species, such as *Q. pubescens* Willd., *Q. cerris* L., *Ulmus minor* Mill. and *Acer monspessulanum* L., are found on the cooler slopes.

Our analysis covers the period between the 3rd century BC and the 13th century AD, from the Roman Period to the Late Middle Ages, with a brief hiatus in the 1st century AD and a longer break of 500 years between the mid-5th and the entire 9th centuries AD. For this area, the archaeological evidence testifies to intense human presence especially in the last 3000 years gravitating around the copper, iron and lead mines of the Metalliferous Hills and the island of Elba (Corretti and Benvenuti, 2001). With the spread of Etruscan civilisation in the 9th and 8th centuries BC, the coastal strip became the main metal-working area in Etruria (Acconcia and Milletti, 2009; Chiarantini et al., 2009). Roselle, Vetulonia and Populonia were the main Etruscan settlements (Vander Poppen, 2008); Populonia, thanks to its coastal location, soon became the centre for smelting iron ore (Cambi and Acconcia, 2011; Cambi and Botarelli, 2004).

In the 3rd century BC, the Romans started to extend their control to northern Etruria (Harris, 1971); in the territory of Populonia, the activity of metal-working reached its zenith (Dallai, 2000), after which, during the Civil Wars, it came to a definitive halt in the 1st century BC (Cambi and Acconcia, 2011). With the decline of Populonia, the network of settlements was re-organised and, between the 1st century BC and 1st century AD, archaeological evidence shows the maximum development of rural settlements in the valleys from Cecina to the River Ombrone (Cambi and Botarelli, 2004; Citter, 1996; Dallai, 2003b; Vaccaro, 2008). In the following century, however, the re-organisation of the Roman economy resulted in a new distribution of industrial activity which led to a sharp decrease in settlement population size (Citter, 1996; Dallai, 2003b; Vaccaro, 2008). Between the end of the 1st and the whole of the 3rd centuries AD, Donoratico belonged to this Roman system of settlements (Bianchi, 2005).

The Late Roman Age experienced a further decline in settlements (Dallai, 2003b; Vaccaro, 2008). In this context between the 4th and mid-5th centuries AD, Alberese became a commercial port at the ancient mouth of the River Ombrone (Cygielman et al., 2013).

The collapse of the Roman Empire marks the end of settlements on the plains, and at the start of the Middle Ages, the settlements mainly consist of hilltop villages (Dallai, 2003b). Between the 7th and 9th centuries AD, Donoratico was one such village (Bianchi, 2005). From the mid-9th century AD to the 11th century AD, the spread of the feudal system forced the construction of hilltop manors, castles and monasteries and encouraged the resumption of mining, which would continue until the end of the Middle Ages (Grassi, 2013). However, already in the 10th century AD, there began a progressive re-settlement of the lowland areas, especially on the Populonia promontory (Ceccarelli Lemut, 2003; Dallai, 2003a).

Materials and methods

For the period of time dated archaeologically between the 3rd century BC and 13th century AD, from the three sites of Donoratico, Populonia and Alberese, samples were taken from 29 stratigraphic levels (herein stratigraphic units – SUs – or activities – A). The chronological details and types of context are reported in Table 1. In order to reconstruct the local vegetation cover, the contexts were carefully selected among those containing scattered charcoal, resulting from long-term activities and processes (Chabal, 1997; Figueiral and Mosbrugger, 2000). The breaks in the 1st century AD and between the mid-5th and the whole of the 9th centuries AD are because of the abandonment of the three sites and the consequent lack of charcoal samples.

The samples were floated and sieved with 4-mm, 2-mm and 0.5-mm meshes. Charcoal fragments over 4.0 mm were identified by an incident light microscope working between 100× and 1000× magnification, referring both to wood atlases (Abbate Edlmann et al., 1994; Greguss, 1955, 1959; Schweingruber, 1990; Vernet et al., 2001) and to our reference collection (Laboratory of Vegetation History and Wood Anatomy, University of Naples Federico II).

For each time interval of the stratified sequence (Table 1), the percentages of each taxon were calculated over the sum total of charcoal samples analysed (Figure 2). In order to better highlight the vegetation changes in our record, we selected key taxa and grouped some of them on the basis of their ecological significance; then, recalculating the percentages of each group from the total of charcoals considered (Figure 3, column ‘Charcoal data’). The evergreen sclerophyllous shrubs (*A. unedo, Rhamnus/Phillyrea, Erica, Cistus, Myrtus, Juniperus* and *Viburnum*) were considered overall as macchia; similarly, the deciduous taxa (*Acer, Cornus, Fraxinus ornus, Ostrya/Carpinus, Ostrya carpinifolia* and *Ulmus*)

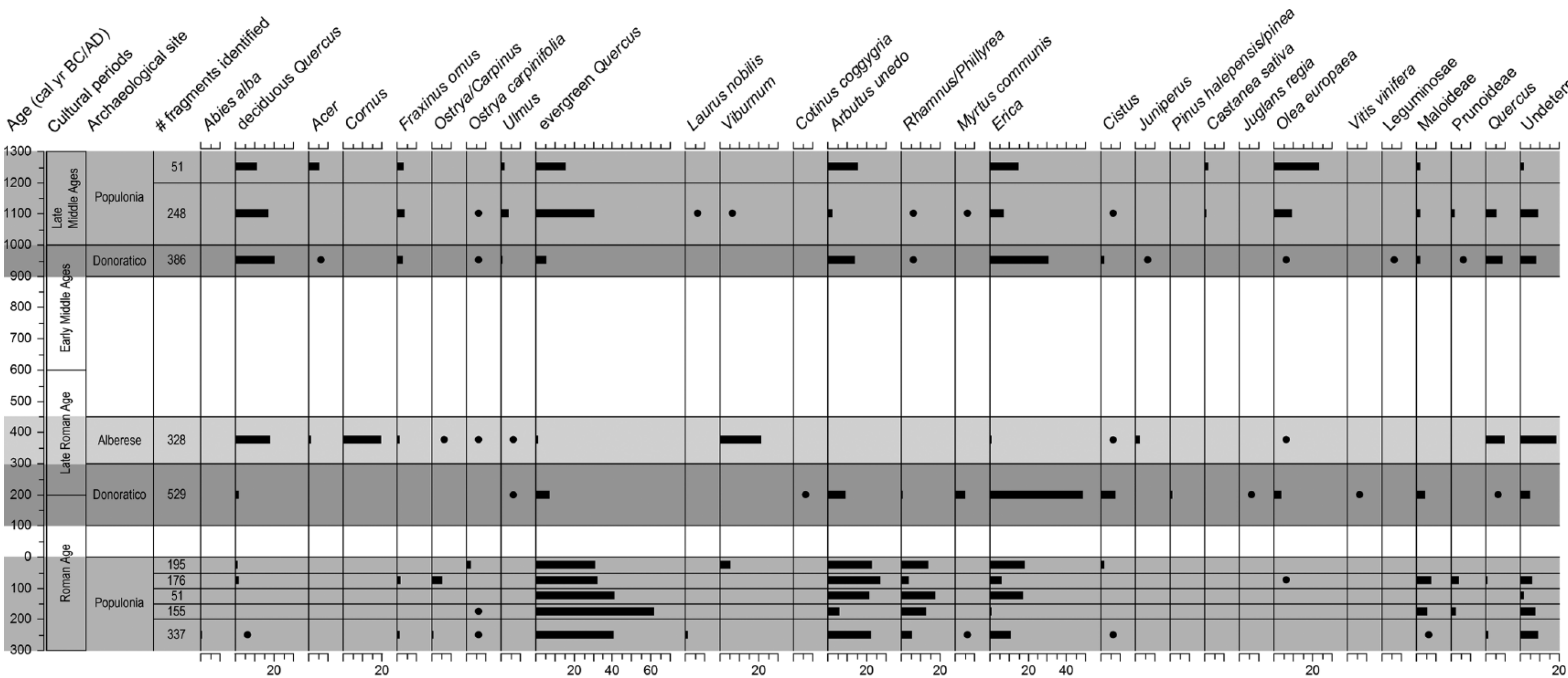

Figure 2. Charcoal analysis diagram of northern coastal Etruria from the archaeological sites of Donoratico, Populonia and Alberese. Small dots represent relative percentages <1%.

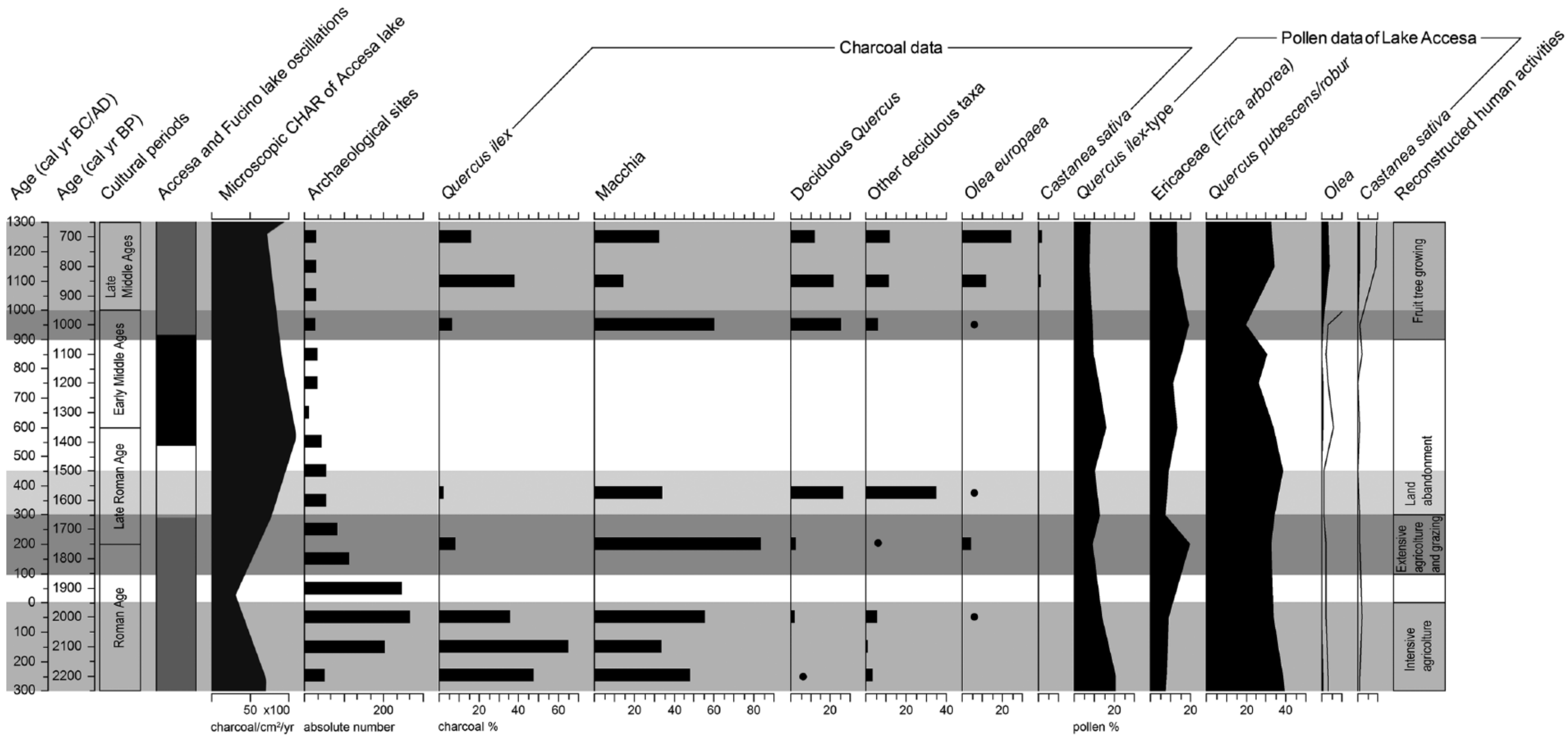

Figure 3. Comparison of key proxies from northern Etruria. Main climatic events in central Italy indicated by the coincidences of low (dark grey squares) and high (light grey squares) Lake Fucino and Lake Accesa levels (from Giraudi et al., 2011); microscopic charcoal accumulation rate (CHAR, #/cm^2/yr) from Lake Accesa (from Vannière et al., 2008); settlement density indicated by the number of archaeological sites (absolute count); charcoal data (%) of selected key taxa and ecological groups (macchia is the sum of *A. unedo, Rhamnus/Phillyrea, Erica, Cistus, Myrtus, Juniperus, Viburnum*; other deciduous taxa is the sum of *Acer, Cornus, Fraxinus ornus, Ostrya/Carpinus, Ostrya carpinifolia* and *Ulmus*); selected key taxa from the Lake Accesa pollen record – zones AC17, core AC3/4 (%, 10× exaggeration is shown by line).

were aggregated; evergreen *Quercus*, deciduous *Quercus, Castanea sativa* and *Olea europaea* were considered on their own.

For comparison with a more regional scale, significant taxa (*Q. pubescens/robur, Q. ilex*-type, Ericaceae, *Castanea sativa* and *Olea*) were selected from the pollen record of Lake Accesa (157 m a.s.l. about 20 km inland) for the period between 2250 and 750 cal. yr BP (zones AC17 – core AC3/4). The pollen diagram was plotted against the calibrated age scale by using the software C2 (Juggins, 2003) with raw data kindly provided by Dr Ruth Drescher-Schneider (Figure 3, column 'Pollen data').

The intensity of soil use was tentatively determined by simply summing the number of settlements detected by archaeological field surveys in the last 30 years (Figure 3, column 'Archaeological sites') between the south-western slopes of the Metalliferous Hills and the alluvial plains of River Cornia (Botarelli, 2004; Cambi et al., 1994; Casini, 2004; De Tommaso, 1998; Dallai, 2003b; Fedeli, 1983), River Pecora (Cambi et al., 1994), River Bruna and River Ombrone (Cambi et al., 1994; Marasco, 2013; Vaccaro, 2008), amounting to a total area of about 1660 km^2 (Figure 1).

Results

In all, 2456 charcoal samples were detected; analysis provided the identification of 25 taxa (Figure 2). In total, 14 taxa are common to all three sites.

Roman Period (between the 3rd and the end of the 1st centuries BC)

For this historical phase, the charcoal data concern the site of Populonia, and 914 samples were analysed (Figure 2): the 337 charcoal samples dating to the 3rd century BC indicate that evergreen *Quercus* (40.9%) was the most common taxon at the time, together with *A. unedo* (22.8%) and *Erica* (11.3%). None of the deciduous taxa exceed 2%. *Laurus nobilis* (1.8%) and *Abies alba* (1.2%) were also found.

The first half of the 2nd century BC is represented by 155 charcoal samples: evergreen *Quercus* is still the dominant taxon (61.9%), while among the shrubs, the most common taxon is *Rhamnus/Phillyrea* (12.9%). Of the deciduous taxa, only *Ostrya carpinifolia* is recorded (<1%). The second half of the 2nd century BC yielded 51 samples, confirming the presence of the same taxa, with the predominance of evergreen *Quercus*.

The period from 100 to 50 BC yielded 176 samples. Sclerophyllous evergreens are always dominant in this period: evergreen *Quercus* accounts for 32.4%, while shrubs reach as high as 37.6%, with *A. unedo* being dominant (27.3%). In this interval of time, deciduous taxa as a whole reach 10.3%: of the latter, *Ostrya/Carpinus* is the best represented (5.7%), while deciduous *Quercus* slightly exceeds 2%. *Olea europaea* is below 1%. In the latter half of the 1st century BC, 195 charcoal samples were analysed. Shrub taxa broadly dominate (63.7%), with *A. unedo* accounting for 23.1% and *Erica* 18.5%, while evergreen *Quercus* accounts for 31.3%. Deciduous taxa are poorly represented, with only *O. carpinifolia* (2.6%) and deciduous *Quercus* (1.5%).

Late Roman Period (between the 2nd and mid-5th centuries AD)

For this period, 857 charcoal samples from the sites of Donoratico and Alberese were analysed (Figure 2). The Donoratico data fall between the Roman and Late Roman Period. The archaeological dating is not precise, with dates spanning the period between the 2nd and the end of the 3rd centuries AD. The 529 samples analysed show low values of evergreen *Quercus* (7.2%) and a more marked presence of evergreen sclerophyllous shrubs dominated by *Erica* (49%). The only deciduous trees recorded are *Quercus* (2.3%) and *Ulmus* (<1%). *Pinus halepensis-pinea* (1.3%) is also present. *O. europaea* does not exceed 5%, while *Juglans regia* and *Vitis vinifera* are both <1%. By contrast, the Alberese data span the 4th and mid-5th centuries AD. The 328 charcoal samples analysed show a completely different situation: deciduous taxa exceed 40% overall, including *Cornus* (19.8%) and deciduous *Quercus* (18.6%). Evergreen vegetation chiefly consists of *Viburnum* (21.6%), while evergreen *Quercus* and *Erica* are both below 2% and *O. europaea* <1%.

Early Middle Ages (10th century AD)

For this historical phase, charcoal data (386 samples) come from the Donoratico site (Figure 2). They indicate the strong presence of *Erica* (31.1%), followed by *A. unedo* (14%). Evergreen *Quercus* accounts for 5.7%. Deciduous taxa total 31.7%, with deciduous *Quercus* (20.7%) dominating. *O. europaea* is recorded (<1%).

Late Middle Ages (between the 11th and 13th centuries AD)

For this historical phase, the charcoal data concern the site of Populonia, and overall 299 samples were analysed (Figure 2). The first sequence of data concerns a settlement phase dating between the 11th and 12th centuries AD. The 248 samples analysed indicate the strong presence of evergreen *Quercus* (30.6%), while shrubs account for 12.1% overall, with *Erica* reaching 7.3%. The deciduous taxa account for 26.5%, with deciduous *Quercus* dominant (17.3%); other deciduous tree taxa, such as *Ulmus, Fraxinus ornus* and *O. carpinifolia* are also identified. *O. europaea* reaches appreciable values for the first time (9.7%), while *Castanea sativa* first appears in the anthracological record, slightly exceeding 1%. The 13th-century data concern sporadic frequentation of the ruins of the Roman city. The few samples analysed (51) show the presence of evergreens: evergreen *Quercus, Erica* and *A. unedo* are all found with at least 15%. The deciduous taxa, including *Quercus* (11.8%), reach 23.2% overall. Finally, it is worth noting that *O. europaea* exceeds 20% and *C. sativa* reaches 2%.

Discussion

The landscape of the Roman Period

This part of ancient Etruria became Roman in the 3rd century BC; the main economic activity distinguishing the area throughout the previous Etruscan phase was that of mining and metal-working which began in the 8th century BC, peaked under Romanisation and then momentarily stopped in the 1st century AD. Several archaeologists have suggested that this period of intense mining activity caused major deforestation throughout the coastal area (Corretti, 2009; Hughes, 2005). Previous spot archaeobotanical studies suggested that cutting activities during the Etruscan Period heavily altered the natural state of the pre-existing woodlands (Sadori et al., 2010b).

The samples from the settlement of Populonia date to the 3rd, 2nd and 1st centuries BC, while those from the hilltop of Donoratico are dated between the 2nd and the end of the 3rd centuries AD. Between the 3rd and 1st centuries BC, the anthracological record shows the dominant evergreen *Quercus*, which in this area essentially consists in *Q. ilex*, with several sclerophyllous macchia shrubs; deciduous taxa are very poorly represented (Figure 3). From the 2nd century AD to the end of the 3rd century AD, evergreen macchia shrubs were abundant (*c.* 84%), while *Q. ilex* stood at *c.* 8%. Deciduous taxa compared with the previous phase are even less represented (Figure 3).

Overall, during these 600 years, *Q. ilex* forest initially seems to dominate the landscape. The forest then seems to contract appreciably, indicating a change to more open macchia formations in which *Erica* is dominant. Interestingly, the pollen sequence of Lake Accesa showed the same dynamic (Figure 3). Ericaceae start to increase at *c.* 2000 cal. yr BP (mid-1st century BC) and culminate at *c.* 1750 cal. yr BP (early 3th century AD), while *Q. ilex* declined. The expansion of the macchia might have been triggered by a widespread climatic event; indeed, the period in question is characterised by dry conditions as shown by low lake levels both at Lake Accesa and Lake Fucino, recorded also on a wider scale in the central Mediterranean and Anatolian lakes, corresponding to the warm bond interval at *c.* 2700–1800 cal. yr BP (Dermody et al., 2012).

Between the 3rd century BC and 3rd century AD, evergreen shrublands increased in several regions: from *c.* 2100 cal. yr BP (mid-2nd century BC), pollen data indicate the spread of macchia in south-eastern Italy, including the Gargano Peninsula (Caroli and Caldara, 2006) and Salento (Di Rita and Magri, 2009), as well as in central Sicily (Sadori et al., 2013) and in western and south-eastern coastal Sicily (Calò et al., 2012; Noti et al., 2009; Tinner et al., 2009). On the other hand, pollen data also indicate for the same period a substantial stability in the forest cover, as in the case of the Versilia Plain on the Tyrrhenian coast 100 km further north of our study area (Bellini et al., 2009; Colombaroli et al., 2007); a widespread deciduous oak forest was present along the lower Tyrrhenian coast in Latium (Goiran et al., 2014; Sadori et al., 2014) and around Naples (Allevato et al., 2010; Russo Ermolli et al., 2014). Also outside Italy, some areas like the southern Balkan Peninsula on the coasts of Acarnania (Jahns, 2004) and Attiki (Kouli, 2012) were unaffected by any forest decline. The evidence of different dynamics in a uniform climatic phase could suggest that changes in the vegetation cover may have been induced by non-climatic factors.

Closer analysis of the historical context may be able to supply a different interpretation. Archaeological evidence concerning the Romanisation of coastal northern Etruria indicates a period of intense human activity (Cambi and Botarelli, 2004; Cambi and Acconcia, 2011; Dallai, 2000), thanks to the number of archaeological sites discovered (Figure 3): from the 2nd century BC onwards, there emerges a complex network of settlements consisting of villas and farms which increased threefold compared with the previous century, reaching its maximum expansion between the 1st century BC and 1st century AD (Botarelli, 2004; Dallai, 2003b; Vaccaro, 2008). In our opinion, our data essentially reflect growing human impact along the northern Etrurian coast: this major presence in the area coincides with the minimum frequency of forest fires testified by microcharcoal in the record at Lake Accesa throughout the whole study period (Figure 3). This may be ascribed to greater area control and land management whereby accumulation of dead biomass is prevented, thereby reducing the fire risk (Tinner et al., 1998).

Between the 2nd and 3rd centuries AD, the charcoal data indicate a forest landscape around Donoratico in which macchia vegetation prevails, while *Q. ilex* drops to fairly low values (Figure 3). Both these data coincide with what is indicated in the pollen diagram (peak of Ericaceae associated with a minimum of *Q. ilex*-type; Figure 3). Deciduous *Quercus* and deciduous trees generally reach the minimum in the anthracological diagram, while they appear more stable in the Lake Accesa pollen diagram which may be affected by the fact that the lake is further inland and higher above sea level. According to the census of the archaeological sites, in the above two centuries, there is a decline in the number of settlements, with fewer than half the number active in the previous century (Figure 3). However, for this period, the archaeologists discuss of a new form of land management in Etruria, called *latifundium*, which concentrates extensive landed property in the hands of a few landowners (Cambi, 1993; Citter, 1996; Vaccaro, 2008) who manage from their farmsteads extensive production based on cereals and livestock (Carandini, 1985; Regoli, 2002). Thus, the great development of macchia and the contraction of tree species can well be interpreted as the effect of overgrazing. The microscopic charcoal accumulation rate in the sediment of Lake Accesa indicates an increase in fires from the mid-1st century AD, which could be interpreted as evidence for the use of fire related to pasturage. It is worth noting that, on the basis of these data, it seems evident that during the time interval between the 2nd and 3rd centuries AD, there was greater impact on the forest cover, even compared with the Etruscan Period in which the area's economy was based on mining and metal-working (Botarelli, 2004; Cambi and Acconcia, 2011; Cambi and Botarelli, 2004).

For the final part of the Roman Period, between the 4th and mid-5th centuries AD, the anthracological record comes from the river port of Alberese and shows deciduous *Quercus* as the dominant tree (*c.* 27%) with other deciduous taxa such as *Cornus* (Figure 3). The percentage of macchia shrubs halved compared with previous phase; of these, only *Viburnum* reached appreciable values, while *Q. ilex* continued to be scarce. The importance of deciduous vegetation which reached *c.* 60% overall is in agreement once again with the vegetation picture shown by the pollen sequences of Lake Accesa (Figure 3), which indicates after *c.* 1750 cal. yr BP (early 3rd century AD) the increase in deciduous *Quercus* until *c.* 1500 cal. yr BP (mid-5th century AD) when it reached its maximum percentage in the time span considered.

The expansion of deciduous species is also recorded in Etruria, 100 km further north, at Lake Massaciuccoli (Colombaroli et al., 2007) between the 3rd and 5th centuries AD. The deciduous forest cover also increased along more southern sites on Tyrrhenian Sea, such as in Latium (Sadori et al., 2010a) and central Sicily (Sadori et al., 2013). On Adriatic Sea, a similar situation has been recorded in the Salento Peninsula (Di Rita and Magri, 2009) and along the South Dalmatian coast (Jahns and Van Den Bogaard, 1998). The expansion of deciduous vegetation to the detriment of evergreens in the Mediterranean during the Holocene has often been explained climatically with humid peaks in the cooler climatic phases (Colombaroli et al., 2009). However, in this case, the spread of deciduous vegetation falls within a dry phase detected in various European and Mediterranean regions (Magny et al., 2013; Peyron et al., 2013), which corresponds locally to the lowest level at Lake Accesa in the last 2500 years (Magny et al., 2007). Therefore, a causal relationship with climate being behind the expansion of deciduous species detected by our charcoal data at the end of the Roman Age should be excluded. A possible cause is suggested by the trend in the number of settlements which continued to fall between the 4th and mid-5th centuries AD (Figure 3) because of progressive depopulation (Vaccaro, 2008). This abandonment could have triggered the forest cover change.

In the Mediterranean, the record of successional processes in progress in the abandoned fields during the second half of the previous century indicates the key role played by deciduous oaks (Quézel and Médail, 2003). The phenomenon of recent rural depopulation has led to the development of deciduous oaks in formerly cultivated lands. This process has been described in the northern areas of the Mediterranean basin, especially in Provence (Barbero et al., 1990; Tatoni et al., 2004), but this is also happening at lower latitudes such as in south-eastern Sicily (Di Pasquale et al., 2004). Deciduous oaks have in fact a greater competitive potential than evergreen oaks in the processes of spatial occupation in abandoned fields (Barbero et al., 1990; Di Pasquale and Garfì, 1998). The deciduous expansion phase which characterises the Late Roman Age may thus have been caused in Etruria, as in other regions of the Mediterranean, by rural depopulation at the end of the Roman Empire and, more generally, by the abandonment of areas hitherto cultivated. The appreciable presence of *Cornus* in the anthracological diagram is in this sense important because it is an endozoochorous species which characterises the intermediate phases of forest succession in abandoned areas (Quézel and Médail, 2003). This hypothesis may be useful to account for other periods as well, varying in settlement intensity and human impact from *c.* 5000 cal. yr BP.

Finally, it should be pointed out that the increase in frequency of fires recorded at Lake Accesa also shows in this case a negative relationship with the number of settlements; this could be interpreted as the effect of the increase in potentially combustible biomass caused by a lack of farm management practices being applied to agro-forestry spaces (Tinner et al., 1998).

The landscape of the Middle Ages

The hiatus between the 6th and 10th centuries AD is because of the absence of samples: Populonia shows no regular human frequentation from the end of the 1st century BC to the 11th century AD; the hilltop of Donoratico was abandoned between the mid-4th and 7th centuries AD and sufficient material for analysis is dated from the 9th century AD; the site of Alberese after the 5th century AD was abandoned and covered with alluvial deposit.

At the end of the Early Medieval Period, between the 9th and 10th centuries AD, in the vegetation at Donoratico, there was a considerable presence of macchia, while deciduous *Quercus* was the dominant arboreal taxon to the detriment of *Q. ilex* (Figure 3). The landscape around Donoratico continued to be dominated by deciduous oaks which characterised the previous centuries and which still remain the dominant trees.

As regards Late Medieval times, the Populonia data show a progressive reduction in the forest component and a shift towards a more open macchia environment (Figure 3). The stability of the forest which may be inferred from the Accesa data suggests a change in the vegetation on a local scale (Figure 3). The most interesting information in this last phase concerns olive (*O. europaea*) and chestnut (*C. sativa*).

Olive charcoal data are scarce from the Roman Period to the end of the Early Middle Ages and increase significantly only from the Late Middle Ages onwards (11th and 12th centuries AD), doubling their frequencies in the 13th century AD (Figure 3). Pollen data from Lake Accesa are yet again consistent with our findings and show a percentage constantly below 0.5% until 1000 cal. yr BP (mid-10th century AD), when they increase moderately to a maximum of 5% (Figure 3). On the whole, these data indicate that, before the Late Middle Ages, olive-growing did not belong to the landscape of northern coastal Etruria, but it constituted only small and scattered plots probably located close to farmsteads. This evidence conflicts with the traditional idea of archaeologists and historians who point to widespread olive cultivation in Etruria between the 3th century BC and 1st century AD during the Roman Republic and Early Empire (Barbieri, 2010; Brun, 2011; Carandini, 1985). On a broader spatial scale, the Italian pollen data seem to confirm a scant presence of olive in the Roman Period in many areas which are today given over to olive-growing, both in central Italy (Bellini et al., 2009; Colombaroli et al., 2007; Mercuri et al., 2002), southern Italy (Caroli and Caldara 2006; Di Rita and Magri, 2009; Russo Ermolli and Di Pasquale, 2002) and Sicily (Calò et al., 2012; Noti et al., 2009; Sadori et al., 2013; Tinner et al., 2009). Medieval historians also partly confirm our findings: for central Italy, in particular, the documents demonstrate that only from the end of the 14th century AD was there a major, definitive development of olive farming (Cortonesi, 2005). It has to be stressed that olive farming in central Italy became established precisely in the centuries of the 'Little Ice Age': this would confute the hypothesis posited by several researchers who tentatively explained the scant presence of olive farming in the Roman Period with the recurrence of cold climatic phases (Di Rita and Magri, 2009).

Chestnut shows a very similar trend to that of olive: it appears in the 11th century AD in very low percentages and again closely matches the data from Lake Accesa which show that chestnut begins to spread a little before, starting from *c.* 1000 cal. yr BP (mid-10th century AD). Both proxies yield an extremely weak signal, even if we know that in the immediate neighbourhood on the Metalliferous Hills, less than 100 km from our study area, chestnut was present at least from the 7th century AD, where it was essentially used for timber (Buonincontri et al., 2014; Di Pasquale et al., 2008). The use of timber has been clearly inferred by means of charcoal data in central and southern Italy at least until the Early Middle Ages (Allevato et al., 2012a; Di Pasquale et al., 2010).

Various pollen sequences up and down peninsular Italy document, from *c.* 1000 cal. yr BP onwards, a great expansion of chestnut (Branch and Marini, 2013; Mercuri et al., 2013; Noti et al., 2009; Sadori et al., 2013; Tinner et al., 1999; Vescovi et al., 2010), contradicting the theory of the spread of this plant between the Late Roman Age and the Early Middle Ages (Conedera et al., 2004; Rottoli, 2014). The extremely low value yielded by charcoal analysis in northern Etruria and the slight rise in chestnut pollen from Lake Accesa would constitute evidence, in this case, of a landscape in expansion, and probably dates the time during which chestnut becomes a food crop 'globally' (Quirós Castillo, 1998). As in the case of olive, the emergence of such landscapes is thus Late Medieval and may well be attributed to the set-up of a new economic organisation with the establishment of the feudal economic system (Wickham, 2005) and later to the establishment of the political system of the *Communi* (Cortonesi, 2005; Wickham, 1988), which led to the need to satisfy a rising demand for food and luxury products (Bosi et al., 2009).

Conclusion

Archaeological charcoal data proved a useful proxy for the reconstruction of the history of vegetation in relation to human activities, both in their exceptional space—time definition and because they allow greater integration with human history. This work highlighted the contribution of a multiproxy approach. The potential shown by the integrated comparison of archaeological charcoal and pollen suggests that this type of approach should be systematically used where possible since it allows the data to be interpreted much more precisely and effectively.

As regards the changes in the forest cover and landscape in this part of central Italy facing the Tyrrhenian coast, our data were able to shed light on the following points:

- Metallurgy which was the hallmark of our study area for about eight centuries (between the 8th and 1st centuries BC) appears to have had less impact on the woody vegetation than that attributed to an economy essentially based on livestock grazing over two centuries (2nd and 3rd centuries AD);
- The transition from sclerophyllous to deciduous experienced by Etruria starting from the end of the Roman Period (4th and mid-5th centuries AD) was not caused by climate but by economic and cultural factors which led to a long phase of land abandonment;
- The expansion of olive and chestnut in the landscapes of central Italy along the Tyrrhenian seaboard only began in the Late Medieval Period (from the 11th century AD) and not in the Roman Period. This means that extensive cultivation of chestnut and olive has very recent origins and should be attributed to one and the same macro-factor.

In general, the changes in vegetation cover which we found all appear independent of climate and strictly connected to economic and social dynamics characterising the history of this part of Etruria. This interpretation appears applicable to various changes in vegetation occurring at the same time and in the same fashion in other regions of the central Mediterranean, and thus may be seen to have more than mere local validity.

Acknowledgements

We are indebted to Dr Ruth Drescher-Schneider for providing raw pollen data from Lake Accesa. We wish to express our gratitude to the archaeologists for providing us with botanical materials, documentation and information about the archaeological stratigraphy: Dr A Sebastiani of the University of Sheffield (Alberese), Professor G Bianchi (Donoratico) and Dr C Mascione (Populonia) of the University of Siena.

Funding

Part of this work was carried out in the framework of the project 'Vegetation History of the Maremma Regional Park' in cooperation with the Maremma Regional Park. MB was supported by funds from the NURSE project granted to AS at the Department of Agriculture, University of Naples Federico II.

References

Abbate Edlmann ML, De Luca L and Lazzeri S (1994) *Atlante anatomico degli alberi e arbusti della macchia mediterranea* (Relazioni e monografie agrarie subtropicali e tropicali 114). Firenze: Istituto Agronomico per l'Oltremare.

Acconcia V and Milletti M (2009) Pratiche metallurgiche e circolazione di saperi all'origine di Populonia. In: Cambi F, Cavari F and Mascione C (eds) *Materiali da costruzione e produzione del ferro. Studi sull'economia populoniese fra periodo etrusco e romanizzazione*. Bari: Edipuglia, pp. 141–147.

Allevato E, Buonincontri MP, Vairo MR et al. (2012a) Persistence of the cultural landscape in Campania (Southern Italy) before the AD 472 Vesuvius eruption: Archaeoenvironmental data. *Journal of Archaeological Science* 39(2): 399–406.

Allevato E, Impagliazzo S, Passariello I et al. (2012b) Holocene palaeofires in tropical alpine environments of northern Andes: Climate relations by soil charcoal analysis. *Quaternary International* 289: 71–77.

Allevato E, Russo Ermolli E, Boetto G et al. (2010) Pollen-wood analysis at the Neapolis harbour site (1st–3rd century AD, southern Italy) and its archaeobotanical implications. *Journal of Archaeological Science* 37(9): 2365–2375.

Asouti E and Austin P (2005) Reconstructing woodland vegetation and its exploitation by past societies, based on the analysis and interpretation of archaeological wood charcoal macro-remains. *Environmental Archaeology* 10: 1–18.

Barbero M, Bonin G, Loisel R et al. (1990) Changes and disturbances of forest ecosystems caused by human activities in the western part of the mediterranean basin. *Vegetatio* 87: 151–173.

Barbieri G (2010) Frantoi romani fra Toscana e Lazio. Un caso singolare di impianto produttivo nei pressi di Viterbo. In: *Eleiva Oleum Olio. Le origini della viticoltura in Toscana: nuovi percorsi di ricerca tra archeologia, botanica e biologia molecolare. Atti della Giornata di Studi* (ed G Barbieri, A Ciacci and A Zifferero), S. Quirico d'Orcia, Siena, 8 December 2007, pp. 71–84. San Quirico d'Orcia, Siena: Editrice DonChisciotte.

Bellini C, Mariotti Lippi M and Montanari C (2009) The Holocene landscape history of the NW Italian coasts. *The Holocene* 19(8): 1161–1172.

Bianchi G (2005) Castello di Donoratico (LI). In: Francovich R and Valenti M (eds) *Archeologia dei Paesaggi Medievali. Relazione progetto 2000–2004*. Firenze: All'Insegna del Giglio, pp. 128–138.

Biserni G and Van Geel B (2005) Reconstruction of Holocene paleoenvironment and sedimentation history of the Ombrone alluvial plain (South Tuscany, Italy). *Review of Palaeobotany and Palynology* 136(1–2): 16–28.

Bosi G, Mercuri AM, Guarnieri C et al. (2009) Luxury food and ornamental plants at the 15th century A.D. Renaissance court of the Este family (Ferrara, northern Italy). *Vegetation History and Archaeobotany* 18(5): 389–402.

Botarelli L (2004) La ricognizione archeologica nella bassa Val di Cornia. In: Gualandi ML and Mascione C (eds) *Materiali per Populonia 3*. Firenze: All'Insegna del Giglio, pp. 223–235.

Branch NP and Marini NAF (2013) Mid-Late Holocene environmental change and human activities in the northern Apennines, Italy. *Quaternary International*. Epub ahead of print 19 August. DOI: 10.1016/j.quaint.2013.07.053.

Brun JP (2011) L'oléiculture en Italie durant l'Antiquité. In: *L'olivier en Méditerranée, entre histoire et patrimoine. Actes du colloque* (ed A Largueche and S Ben Baaziz), Sousse, 6–10 February 2007, pp. 87–111. Tunis: Centre de Publications Universitaires.

Buonincontri M, Moser D, Allevato E et al. (2014) Farming in a rural settlement in central Italy: Cultural and environmental implications of crop production through the transition from Lombard to Frankish influence (8th–11th centuries a.d.). *Vegetation History and Archaeobotany*. Epub ahead of print 14 January. DOI: 10.1007/s00334-013-0429-8.

Calò C, Henne PD, Curry B et al. (2012) Spatio-temporal patterns of Holocene environmental change in southern Sicily. *Palaeogeography, Palaeoclimatology, Palaeoecology* 323–325: 110–122.

Cambi F (1993) Paesaggi d'Etruria e di Puglia. In: Giardina A and Schiavone A (eds) *Storia di Roma. III.2*. Torino: Einaudi, pp. 229–254.

Cambi F and Acconcia V (2011) A hidden urban landscape: Populonia between survey and excavations. In: *Hidden Landscapes of Mediterranean Europe: Cultural and Methodological Biases in Pre- and Protohistoric Landscape Studies: Proceedings of the International Meeting* (ed M Van Leusen, G Pizziolo and L Sarti; British Archaeological Reports), Siena, 25–27 May 2007, pp. 255–264. Oxford: Archaeopress.

Cambi F and Botarelli L (2004) Il territorio di Populonia fra il periodo etrusco tardo ed il periodo romano: la ricognizione archeologica. *Rassegna di Archeologia: classica e postclassica* 21*B*: 159–169.

Cambi F, Citter C, Guideri S et al. (1994) Etruria, Tuscia, Toscana: la formazione dei paesaggi altomedievali. In: *La storia dell'Alto Medioevo italiano (VI-X secolo) alla luce dell'archeologia. Convegno Internazionale* (ed R Francovich and G Noyé), Siena, 2–6 December 1992, pp. 183–215. Firenze: All'Insegna del Giglio.

Carandini A (1985) Racconto di una villa. In: Carandini A (ed.) *Settefinestre. Una villa schiavistica nell'Etruria romana*, vol. I. Modena: Edizioni Panini, pp. 138–186.

Caroli I and Caldara M (2006) Vegetation history of Lago Battaglia (eastern Gargano coast, Apulia, Italy) during the middle-late Holocene. *Vegetation History and Archaeobotany* 16(4): 317–327.

Casini A (2004) L'indagine archeologica nel territorio campigliese. In: Bianchi G (ed.) *Campiglia: un castello ed il suo territorio. II*. Firenze: All'Insegna del Giglio, pp. 141–166.

Ceccarelli Lemut ML (2003) La Maremma populoniese nel Medioevo. In: Bianchi G (ed.) *Campiglia: Un castello ed il suo territorio. I*. Firenze: All'Insegna del Giglio, pp. 1–126.

Chabal L (1994) Apports de l'anthracologie à la connaissance des paysages passés: Performances et limites. *Histoire et Mesure* IX(3–4): 317–338.

Chabal L (1997) *Forêts et sociétés en Languedoc (Néolithique final, Antiquité tardive). L'anthracologie, méthode et paléoécologie* (DAF 63). Paris: Editions de la Maison des Sciences de l'Homme.

Chiarantini L, Benvenuti M, Costagliola P et al. (2009) Copper production at Baratti (Populonia, southern Tuscany) in the early Etruscan period (9th–8th centuries BC). *Journal of Archaeological Science* 36(7): 1626–1636.

Citter C (1996) Il territorio di Roselle-Grosseto: occupazione del suolo e forme insediative dalla preistoria al medioevo. In: Citter C (ed.) *Grosseto, Roselle e il Prile. Note per la storia di una città e del territorio circostante* (Documenti di Archeologia 8). Mantova: Società Archeologica Padana, pp. 25–45.

Colombaroli D, Marchetto A and Tinner W (2007) Long-term interactions between Mediterranean climate, vegetation and fire regime at Lago di Massaciuccoli (Tuscany, Italy). *Journal of Ecology* 95(4): 755–770.

Colombaroli D, Tinner W, Van Leeuwen J et al. (2009) Response of broadleaved evergreen Mediterranean forest vegetation to fire disturbance during the Holocene: Insights from the peri-Adriatic region. *Journal of Biogeography* 36(2): 314–326.

Colonese AC, Zanchetta G, Fallick AE et al. (2007) Stable isotope composition of Late Glacial land snail shells from Grotta del Romito (southern Italy): Paleoclimatic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology* 254: 550–560.

Conedera M, Krebs P, Tinner W et al. (2004) The cultivation of *Castanea sativa* (Mill.) in Europe, from its origin to its diffusion on a continental scale. *Vegetation History and Archaeobotany* 13(3): 161–179.

Corretti A (2009) Siderurgia in ambito elbano e populoniese: un contributo dalle fonti letterarie. In: Cambi F, Cavari F and Mascione C (eds) *Materiali da costruzione e produzione del ferro. Studi sull'economia populoniese fra periodo etrusco e romanizzazione*. Bari: Edipuglia, pp. 133–139.

Corretti A and Benvenuti M (2001) The beginning of iron metallurgy in Tuscany, with special reference to 'Etruria mineraria'. *Mediterranean Archaeology* 14: 127–145.

Cortonesi A (2005) L'olivo nell'Italia medievale. *Reti Medievali Rivista* 6(2): 2–29.

Cygielman M, Chirico E, Colombini M et al. (2013) River port trade, luxury glass working and temple dedications along the via Aurelia vetus: New excavations in Roman Tuscany. In: *SOMA 2012. Identity and Connectivity: Proceedings of the 16th Symposium on Mediterranean Archaeology*, vol. II (ed L Bombardieri, A D'Agostino, G Guarducci et al). Firenze, 1–3 March 2012, pp. 877–885 (BAR International Series 2581 (II)). Oxford: Archaeopress.

Dallai L (2000) Opifici metallurgici sul promontorio di Piombino: primi dati topografici. In: *II Congresso Nazionale di Archeologia Medievale* (ed GP Brogiolo), Brescia, 28 September–1 October, pp. 194–198. Firenze: All'Insegna del Giglio.

Dallai L (2003a) Indagini archeologiche sul territorio dell'antica diocesi di Massa e Populonia: insediamento monastico e produzione del metallo fra XI e XIII secolo. In: Francovich R (ed.) *Monasteri e castelli fra X e XII secolo: il caso di San Michele alla Verruca e le altre ricerche storico-archeologiche nella Tuscia occidentale. Atti del convegno*. Vicopisano (Pisa), Italy, 17–18 November 2000, pp.113–124. Firenze: All'Insegna del Giglio.

Dallai L (2003b) Prospezioni archeologiche sul territorio della diocesi di Massa e Populonia. L'evoluzione del sistema insediativo fra la tarda antichità ed il medioevo; alcune proposte interpretative. In: *III Congresso Nazionale di Archeologia Medievale* (ed R Fiorillo and P Peduto), Salerno, 2–5 October, pp. 337–343. Firenze: All'Insegna del Giglio.

Dermody BJ, De Boer HJ, Bierkens MFP et al. (2012) A seesaw in Mediterranean precipitation during the Roman Period linked to millennial-scale changes in the North Atlantic. *Climate of the Past* 8(2): 637–651.

De Tommaso G (1998) La villa romana di Poggio del Molino (Piombino, LI). Lo scavo e i materiali. *Rassegna di Archeologia* 15: 119–347.

Di Pasquale G and Garfì G (1998) Analyse comparée de l'évolution et de la régénération de *Quercus suber* et *Q. pubescens* après élimination du patûrage en forêt de Pisano (Sicile sud-orientale). *Ecologia Mediterranea* 24: 15–25.

Di Pasquale G, Di Falco G and Moser D (2008) Analisi archeobotaniche. In: Valenti M (ed.) *Miranduolo in Alta Val di Merse (Chiusdino – SI). Archeologia su un sito di potere del Medioevo toscano*. Firenze: All'Insegna del Giglio, pp. 323–348.

Di Pasquale G, Garfì G and Migliozzi A (2004) Landscape dynamics in South-Eastern Sicily in the last 150 years: The case of the Iblei Mountains. In: Mazzoleni S, Di Pasquale G, Mulligan M et al. (eds) *Recent Dynamics of the Mediterranean Vegetation and Landscape*. Chichester: John Wiley & Sons, pp. 73–80.

Di Pasquale G, Allevato E, Cocchiararo A et al. (2014) Late Holocene persistence of *Abies alba* in low-mid altitude deciduous forests of central and southern Italy: New perspectives from charcoal data. *Journal of Vegetation Science*. Epub ahead of print 28 May 2014. DOI: 10.1111/jvs.12196.

Di Pasquale G, Allevato E, Russo Ermolli E et al. (2010) Reworking the idea of chestnut (*Castanea sativa* Mill.) cultivation in Roman times: New data from ancient Campania. *Plant Biosystems* 144(4): 865–873.

Di Rita F and Magri D (2009) Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: A 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy. *The Holocene* 19(2): 295–306.

Drescher-Schneider R, De Beaulieu JL, Magny M et al. (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: 279–299.

Erdkamp P (2005) *The Grain Market in the Roman Empire: A Social, Political and Economic Study*. Cambridge: Cambridge University Press.

Fedeli F (1983) *Populonia. Storia e territorio*. Firenze: All'Insegna del Giglio.

Figueiral I and Mosbrugger V (2000) A review of charcoal analysis as a tool for assessing Quaternary and Tertiary environments: Achievements and limits. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164(1–4): 397–407.

Finsinger W, Colombaroli D, De Beaulieu JL et al. (2010) Early to mid-Holocene climate change at Lago dell'Accesa (central Italy): Climate signal or anthropogenic bias? *Journal of Quaternary Science* 25(8): 1239–1247.

Giraudi C, Magny M, Zanchetta G et al. (2011) The Holocene climatic evolution of Mediterranean Italy: A review of the continental geological data. *The Holocene* 21(1): 105–115.

Goiran JP, Salomon F, Mazzini I et al. (2014) Geoarchaeology confirms location of the ancient harbour basin of Ostia (Italy). *Journal of Archaeological Science* 41: 389–398.

Grassi F (2013) Insediamenti e risorse minerarie nelle Colline Metallifere alla luce delle ricerche archeologiche. Il Medioevo (VIII-XIV secolo). In: Grassi F (ed.) *L'insediamento medievale nelle Colline Metallifere (Toscana, Italia). Il sito minerario di Rocchette Pannocchieschi dall'VIII al XIV secolo* (BAR International Series 2532). Oxford: Archaeopress, pp. 28–35.

Greguss P (1955) *Identification of Living Gymnosperms on the Basis of Xylotomy*. Budapest: Akademiai Kiado.

Greguss P (1959) *Holzanatomie der Europaïschen Laubhölzer und Straucher*. Budapest: Akademiai Kiado.

Harris VW (1971) *Rome in Etruria and Umbria*. Oxford: The Clarendon Press.

Harris VW (2013) What kind of environmental history for Antiquity? In: Harris VW (ed.) *The Ancient Mediterranean Environment between Science and History*. Boston, MA: Leiden, pp. 1–10.

Horden P and Purcell N (2000) *The Corrupting Sea: A Study of Mediterranean History*. Oxford: Blackwell.

Hughes JD (2005) *The Mediterranean: An Environmental History*. Santa Barbara, CA: ABC-CLIO.

Hughes JD and Thirgood V (1982) Deforestation, erosion, and forest management in Ancient Greece and Rome. *Journal of Forest History* 26(2): 60–75.

Jahns S (2004) The Holocene history of vegetation and settlement at the coastal site of Lake Voulkaria in Acarnania, western Greece. *Vegetation History and Archaeobotany* 14(1): 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(4): 219–234.

Juggins S (2003) C2 User guide. Software for ecological and palaeoecological data analysis and visualisation. Available at: http://www.staff.ncl.ac.uk/staff/stephen.juggins/software/code/C2.pdf (accessed 23 May 2014).

Kouli K (2012) Vegetation development and human activities in Attiki (SE Greece) during the last 5,000 years. *Vegetation History and Archaeobotany* 21(4–5): 267–278.

Magny M, Combourieu-Nebout N, De Beaulieu JL et al. (2013) North–south palaeohydrological contrasts in the central Mediterranean during the Holocene: Tentative synthesis and working hypotheses. *Climate of the Past* 9(5): 2043–2071.

Magny M, De Beaulieu JL, Drescher-Schneider R et al. (2007) Holocene climate changes in the central Mediterranean as recorded by lake-level fluctuations at Lake Accesa (Tuscany, Italy). *Quaternary Science Reviews* 26(13–14): 1736–1758.

Marasco L (2013) *Archeologia dei paesaggi, fonti documentarie e strutture insediative in ambito rurale toscano tra VIII e XI secolo. Nuove indagini archeologiche sul comprensorio costiero dell'Alta Maremma*. PhD Thesis, University of Siena.

Masi A, Sadori L, Baneschi I et al. (2013) Stable isotope analysis of archaeological oak charcoal from eastern Anatolia as a marker of mid-Holocene climate change. *Plant Biology* 15(1): 83–92.

Mercuri AM and Sadori L (2014) Mediterranean culture and climatic change: Past patterns and future trends. In: Goffredo S and Dubinsky Z (eds) *The Mediterranean Sea*. Dordrecht: Springer, pp. 507–527.

Mercuri AM, Accorsi CA 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(4): 263–276.

Mercuri AM, Bandini Mazzanti M, Florenzano A et al. (2013) *Olea, Juglans* and *Castanea*: The OJC group as pollen evidence of the development of human-induced environments in the Italian peninsula. *Quaternary International* 303: 24–42.

Noti R, Leeuwen JFN, Colombaroli D et al. (2009) Mid- and late-Holocene vegetation and fire history at Biviere di Gela, a coastal lake in southern Sicily, Italy. *Vegetation History and Archaeobotany* 18(5): 371–387.

Pelle T, Scarciglia F, Allevato E et al. (2013a) Reconstruction of Holocene environmental changes in two archaeological sites of Calabria (Southern Italy) using an integrated pedological and anthracological approach. *Quaternary International* 288: 206–214.

Pelle T, Scarciglia F, Di Pasquale G et al. (2013b) Multidisciplinary study of Holocene archaeological soils in an upland Mediterranean site: Natural versus anthropogenic environmental changes at Cecita Lake, Calabria, Italy. *Quaternary International* 303: 163–179.

Peyron O, Magny M, Goring S et al. (2013) Contrasting patterns of climatic changes during the Holocene across the Italian Peninsula reconstructed from pollen data. *Climate of the Past* 9(3): 1233–1252.

Quézel P and Médail F (2003) *Ecologie et biogéographie des forêts du bassin Méditerranéen*. Paris: Elsevier.

Quirós Castillo JA (1998) Cambios y transformaciones en el paisaje del Apenino Toscano entre la Antigüedad Tardía y la Edad Media. El castaño. *Archeologia Medievale* 25: 177–197.

Regoli E (2002) La Media e la Tarda Età Imperiale. In: Carandini A, Cambi F, Celuzza MG et al. (eds) *Paesaggi d'Etruria. Valle dell'Albegna, Valle d'Oro, Valle del Chiarone, Valle del Tafone*. Roma: Edizioni di Storia e Letteratura, pp. 218–245.

Roberts N, Brayshaw D, Kuzucuoglu C et al. (2011) The mid-Holocene climatic transition in the Mediterranean: Causes and consequences. *The Holocene* 21(1): 3–13.

Rottoli M (2014) Reflections on Early Medieval resources in northern Italy: The archaeobotanical and archaeozoological data. *Quaternary International*. Epub ahead of print 6 February. DOI: 10.1016/j.quaint.2014.01.014.

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(3): 211–220.

Russo Ermolli E, Romano P, Ruello MR et al. (2014) The natural and cultural landscape of Naples (southern Italy) during the Graeco-Roman and Late Antique periods. *Journal of Archaeological Science* 42: 399–411.

Sadori L, Allevato E, Bellini C et al. (2014) Archaeobotany in Italian ancient Roman harbours. *Review of Palaeobotany and Palynology*. Epub ahead of print 4 March. DOI: 10.1016/j.revpalbo.2014.02.004.

Sadori L, Giardini M, Giraudi C et al. (2010a) The plant landscape of the imperial harbour of Rome. *Journal of Archaeological Science* 37(12): 3294–3305.

Sadori L, Giraudi C, Petitti P et al. (2004) Human impact at Lago di Mezzano (central Italy) during the Bronze Age: A multidisciplinary approach. *Quaternary International* 113(1): 5–17.

Sadori L, Jahns S and Peyron O (2011) Mid-Holocene vegetation history of the central Mediterranean. *The Holocene* 21(1): 117–129.

Sadori L, Mercuri AM and Mariotti Lippi M (2010b) Reconstructing past cultural landscape and human impact using pollen and plant macroremains. *Plant Biosystems* 144(4): 940–951.

Sadori L, Ortu E, Peyron O et al. (2013) The last 7 millennia of vegetation and climate changes at Lago di Pergusa (central Sicily, Italy). *Climate of the Past* 9(4): 1969–1984.

Schweingruber FH (1990) *European Wood Anatomy*. Bern: Paul Haupt.

Tatoni T, Medail F, Roche P et al. (2004) The impact of changes in land use on ecological patterns in Provence (Mediterranean France). In: Mazzoleni S, Di Pasquale G, Mulligan M et al. (eds) *Recent Dynamics of the Mediterranean Vegetation and Landscape*. Chichester: John Wiley & Sons, pp. 107–120.

Tinner W, Ammann B, Conedera M et al. (1998) Pollen and charcoal in lake sediments compared with historically documented forest fires in southern Switzerland since AD 1920. *The Holocene* 8(1): 31–42.

Tinner W, Hubschmid P, Wehrli M et al. (1999) Long-term forest fire ecology and dynamics in southern Switzerland. *Journal of Ecology* 87: 273–289.

Tinner W, Van Leeuwen JFN, Colombaroli D et al. (2009) Holocene environmental and climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy. *Quaternary Science Reviews* 28(15–16): 1498–1510.

Vaccaro E (2008) An overview of rural settlement in four river basins in the province of Grosseto on the coast of Tuscany. *Journal of Roman Archaeology* 21: 225–247.

Vander Poppen RE (2008) *Rural change and continuity in Etruria: A study of village communities from the 7th century* BC *to the 1st century* AD. PhD Thesis, University of North Carolina.

Vannière B, Colombaroli D, Chapron E et al. (2008) Climate versus human-driven fire regimes in Mediterranean landscapes: The Holocene record of Lago dell'Accesa (Tuscany, Italy). *Quaternary Science Reviews* 27(11–12): 1181–1196.

Vannière B, Power MJ, Roberts N et al. (2011) Circum-Mediterranean fire activity and climate changes during the mid-Holocene environmental transition (8500–2500 cal. BP). *The Holocene* 21(1): 53–73.

Vernet JL, Ogereau P, Figueiral I et al. (2001) *Guide d'identification des charbons de bois prehistoriques et recents*. Paris: Editions du CNRS.

Vescovi E, Kaltenrieder P and Tinner W (2010) Late-Glacial and Holocene vegetation history of Pavullo nel Frignano (Northern Apennines, Italy). *Review of Palaeobotany and Palynology* 160(1–2): 32–45.

Wickham C (1988) *The Mountains and the City: The Tuscan Appennines in the Early Middle Ages*. Oxford: The Clarendon Press.

Wickham C (2005) *Framing the Early Middle Ages: Europe and the Mediterranean, 400–800*. New York: Oxford University Press.

Wilson A (2013) The Mediterranean environment in ancient history: Perspectives and prospects. In: Harris VW (ed.) *The Ancient Mediterranean Environment between Science and History*. Boston, MA: Leiden, pp. 259–276.

Zanchetta G, Bini M, Cremaschi M et al. (2013) The transition from natural to anthropogenic-dominated environmental change in Italy and the surrounding regions since the Neolithic: An introduction. *Quaternary International* 303: 1–9.

Zanchetta G, Giraudi C, Sulpizio R et al. (2012) Constraining the onset of the Holocene 'Neoglacial' over the central Italy using tephra layers. *Quaternary Research* 78(2): 236–247.

Zanchetta G, Sulpizio R, Roberts N et al. (2011) Tephrostratigraphy, chronology and climatic events of the Mediterranean basin during the Holocene: An overview. *The Holocene* 21(1): 33–52.