Quaternary International 457 (2017) 113–130

Contents lists available at ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Holocene mountain forest changes in central Mediterranean: Soil charcoal data from the Sila Massif (Calabria, southern Italy)

Daniela Moser [a, b, d, *], Gaetano Di Pasquale [b], Fabio Scarciglia [c], Oliver Nelle [a, d, 1]

[a] *Graduate School "Human Development in Landscapes", Kiel University, Leibnizstrasse 3, 24118 Kiel, Germany*
[b] *Laboratory of Vegetation History and Wood Anatomy, Department of Agriculture, University of Naples Federico II, Via Università 100, 80055 Portici, Italy*
[c] *Department of Biology, Ecology and Earth Sciences (DiBEST), University of Calabria, Via Pietro Bucci - Cubo 15B, 87036 Arcavacata di Rende, CS, Italy*
[d] *Institute for Ecosystem Research, Paleoecology Unit, Kiel University, Olshausenstrasse 75, 24118 Kiel, Germany*

ARTICLE INFO

Article history:
Received 14 June 2016
Received in revised form
22 December 2016
Accepted 28 January 2017
Available online 8 February 2017

Keywords:
Bronze Age
Sila uplands
Climate
Human impact
Deciduous *Quercus*
Pinus laricio

ABSTRACT

Soil charcoal analysis was performed on soil profiles excavated in the area of Cecita Lake on the Sila Massif (Calabria, southern Italy). Charcoals identification, combined with a good number of radiocarbon dating and the pedological analysis of the soils, allowed drawing a detailed history of the Holocene vegetation changes in the area. Five periods characterised by high concentration of radiocarbon dates — mirroring increased fire activity — are documented at ca. 10400-9000 BP, 8200-7200 BP, 5100-3700 BP, 3300-2400 BP and 600 BP to the present. Furthermore, a severe environmental change took place between the Middle Bronze Age and the Final Bronze Age/Iron Age (ca. 3600 to 3000 BP), when the mixed deciduous oak-silver fir woodland, which dominated the landscape until the Early Bronze Age, declined and was substituted by a Calabrian pine forest or by an open landscape. Available climate, pollen and historical/archaeological data are taken into account to investigate the possible causes of the detected environmental change and of the periods of increased fire activity. If climate seems to play a role in the fire regime during the first part of the Holocene, human action seems to be the triggering factor in the environmental change and the fire regime during the Late Holocene.

1. Introduction

In the last two decades, numerous studies on the vegetation history of the Mediterranean region have been undertaken (e.g. Jahns, 1993; Jahns and van den Bogaard, 1998; Yasuda et al., 2000; Roberts et al., 2001; Allen et al., 2002; Carrión et al., 2007; Drescher-Schneider et al., 2007; Di Rita and Magri, 2009; Calò et al., 2012; Sadori et al., 2013; Zapata et al., 2013). Special issues of different journals (e.g. The Holocene 21(1); Quaternary International 303) contributed in drawing the attention to the topic of the mutual influence of climate changes and human impact in shaping the Mediterranean landscape and vegetation. In fact, the millenary presence of human settlements in the Mediterranean basin deeply contributed in the formation of its specific cultural landscape. If in the first part of the Holocene until ca. 6500 BP, climate is seen as the main factor influencing vegetation changes in the Mediterranean region, after this date the human action become an undeniable factor in modifying the landscape (see the concept of mid-Holocene Mediterranean "mélange" by Roberts et al., 2011). The synergic action of humans and climate on the vegetation in the last part of the Holocene makes difficult to disentangle the question if the recorded vegetation changes are climate or human driven and to evaluate in which extent the two factors acted on the environment and at which scale. Recent studies demonstrated the existence of regional patterns of climate trend across the Mediterranean (Berger and Guilaine, 2009; Magny et al., 2012; Zanchetta et al., 2013), further complicating the data interpretation. The Italian peninsula, in particular, seems to show opposite trends of climate conditions north and south of 40° latitude during the Holocene (Magny et al., 2013; Peyron et al., 2013) and, with its position in the centre of the Mediterranean, is located between the two different climatic systems of the western and eastern part of the basin (Roberts et al., 2011). Based on these assumptions, the combination of regional

---

* Corresponding author. Graduate School "Human Development in Landscapes", Kiel University, Leibnizstrasse 3, 24118 Kiel, Germany.

E-mail addresses: dmoser@gshdl.uni-kiel.de (D. Moser), gaetano.dipasquale@unina.it (G. Di Pasquale), fabio.scarciglia@unical.it (F. Scarciglia), Oliver.Nelle@rps.bwl.de (O. Nelle).

[1] Present address: Regierungspräsidium Stuttgart, Landesamt für Denkmalpflege, Referat 84.1 Dendrochronologisches Labor, Fischersteig 9, 78343 Gaienhofen-Hemmenhofen, Germany.

http://dx.doi.org/10.1016/j.quaint.2017.01.042
1040-6182/

and local studies together with a multidisciplinary approach – comparing environmental proxies not subjected to human influence and historical/archaeological data - seem to be fundamental to unravel environmental changes and to evaluate the causes of such changes.

Today, we can count on a good number of studies concerning pollen-based reconstruction of vegetation history in Italy (e.g. Russo Ermolli and Di Pasquale, 2002; Valsecchi et al., 2006; Caroli and Caldara, 2007; Drescher-Schneider et al., 2007; Noti et al., 2009; Tinner et al., 2009; Kaltenrieder et al., 2010; Sadori et al., 2011; Joannin et al., 2014). To the high number of pollen-based studies does not correspond a likewise number of studies based on soil charcoal analysis, which represents a unique tool to investigate local fire events and vegetation changes with a high-detailed spatial resolution (Thinon, 1978) and possibly without the human selection characterising archaeological charcoals (Théry-Parisot et al., 2010). Unlike other areas of Europe, where soil charcoal analysis was applied in different contexts (for a review see Nelle et al., 2013), in Italy only few studies were published so far (Di Pasquale and Mazzoleni, 2002; Favilli et al., 2010; Egli et al., 2012; Compostella et al., 2013).

In this paper, the results of soil charcoal analysis carried out in the area of Cecita Lake on the Sila Massif (southern Italy) are presented. The study represents a contribution to the Holocene vegetation history of the area and it is important in relation to the almost complete absence of environmental studies aimed at past-vegetation reconstruction, which are limited to the recent work of Joannin et al. (2012) and few old investigations (Ferrarini, 1978; Schneider, 1985).

Starting from 2008, charcoal and pedological analyses were carried out at two archaeological sites dated to Neolithic and Roman Age located along the shores of Cecita Lake. The results (Pelle et al., 2013a, 2013b) showed the predominance of deciduous *Quercus* charcoal in the Neolithic, while during Roman times *Pinus* group *sylvestris* dominates. The data suggest a shift from an oak-dominated deciduous forest to a pine forest during the time between Neolithic and Roman Age. Based on these results, we enlarged the investigation, performing soil charcoal analysis on soil profiles excavated in the area around Cecita Lake and combining them with a good number of AMS radiocarbon dating. Our aims were: 1) to provide a record of the past vegetation not connected to archaeological settlements and indeed not directly influenced by human selection; 2) to better understand the timing of the vegetation change; 3) to advance hypothesis about the causes of the change to clarify if it was caused by a climate change or the anthropogenic impact.

2. Regional setting

2.1. Soil, climate and vegetation settings

Cecita Lake (39° 9′ 36″ N; 15° 56′ 38″ E) is an artificially dammed lake build up in the 50s in the place of a Pleistocene paleo-lake. It is located in the Sila Grande Massif (Calabria, southern Italy) at about 1150 m a.s.l. The Sila Massif is part of the Calabrian Apennine, which constitutes the far end of the Italian Apennines (Fig. 1). The lake is surrounded by three levels of fluvio-lacustrine terraces, in turn entrenched in an upland paleolandscape consisting of flat to gently-rolling planation surfaces, originated from Middle to Late Pleistocene – Holocene differential tectonic uplifts and ranging from about 1000 to 1700 m a.s.l. (Scarciglia et al., 2005). The area around the lake displays the presence of a widespread soil type - developed on fluvio-lacustrine deposits and plutonic bedrock and characterized by the contribution of late Pleistocene to Holocene fine volcanic ash – which represents a pedostratigraphic marker in the Sila uplands, the so-called "Cecita Lake geosol" (Scarciglia et al., 2008; Pelle et al., 2013b).

The study area is characterised by a temperate humid mountain Mediterranean climate with rainy autumns and winters and short dry summers. Mean annual precipitations are about 1230 mm. Mean annual temperature is 8–9 °C, with a mean minimum temperature in the coldest month (January) of −2 °C and a mean maximum temperature in the hottest month (August) of 25 °C (Fig. 1. Cecita lake weather station: Ciancio, 1971).

Nowadays the vegetation cover is composed mainly by grassland and cultivated fields. The lower vegetation belt (from 600 to 1100 m a.s.l.) is characterised by mixed deciduous mesophilous forests dominated by *Quercus cerris* and by widespread *Castanea sativa* woodlands (Bernardo et al., 1991). The upper vegetation belt (above 1100 m a.s.l.) is characterised by *Fagus sylvatica* forests, sometimes associated with *Abies alba* (Barbero and Quézel, 1975; Bernardo et al., 2010), and especially by high mountain coniferous forests with a strong predominance of *Pinus nigra* ssp. *laricio* (hereafter called *Pinus laricio* or Calabrian pine; Bernardo et al., 1991, 2010). Until a recent past, *Quercus cerris* and *Fagus sylvatica* woodlands were present both as coppices and as high forests (e.g. Menguzzato, 2013). The frequent abandonment of the coppices in the last 50 years led to their shift into high forests (e.g. Avolio and Ciancio, 1991; Ciancio et al., 2007). *Castanea sativa* experienced an inverse trend with the abandonment of the high chestnut woodlands for fruit production and their transformation into coppices (Avolio et al., 2009–2010). *Pinus laricio* is an endemic tree in Calabria (Quézel and Médail, 2003), managed for over a century with a particular form of selection cutting (Ciancio et al., 2006), and constitutes nowadays a typical element of the Sila landscape. Nevertheless, except scattered stands of old-growth pine forest (Ciancio et al., 2010), the present forests are the results of reforestation programs for soil conservation started in the 50s (Costantini, 1993) and of a spontaneous reforestation that followed the abandonment of the mountain areas in the last century after several and long-term phases of intense forest clearance.

2.2. Historical and archaeological settings

The Sila Massif has a long history of human presence: archaeological findings testify human activities since the Lower Palaeolithic about 700000-500000 years ago (Palma di Cesnola, 2004). Recent excavations on the shores of Cecita Lake (Marino and Taliano Grasso, 2010) brought to light numerous settlements (Fig. 1) dated to the Late Neolithic and Early Eneolithic, when agriculture and grazing, as well as mining, spinning, fishing and woodlands exploitation were practiced. Cecita Lake, moreover, is located along the natural route connecting the Ionian coast to the Crati Valley that was probably used during Neolithic times for the trade of the obsidian coming from Lipari (Ammerman, 1979). Settlements dated to the Early and Middle Bronze Age are also documented in the area (Marino and Taliano Grasso, 2010), devoted to agriculture and grazing and to the exploitation of the local mining resources (Marino and Pacciarelli, 1996). For the Greek Age, archaeological data testify contacts with important Greek cities of the Magna Graecia (Marino and Taliano Grasso, 2010). The presence of the Bruttians, an Italic population that establishes on the Sila Massif from about 350 to 200 BCE is also documented: exploitation and trade of timber, pitch and salty fish, together with grazing, were the most important activities (Guzzo, 1989). The Bruttians were finally defeated by the Romans, which annexed the Sila to the state property and started to deeply exploit the natural resources of the area, such as forests, pitch and pasture (Lombardo, 1989). Lombard settlements were also present nearby the lake (Roma, 2010): in fact, in the Early Middle Ages the border between Byzantine and

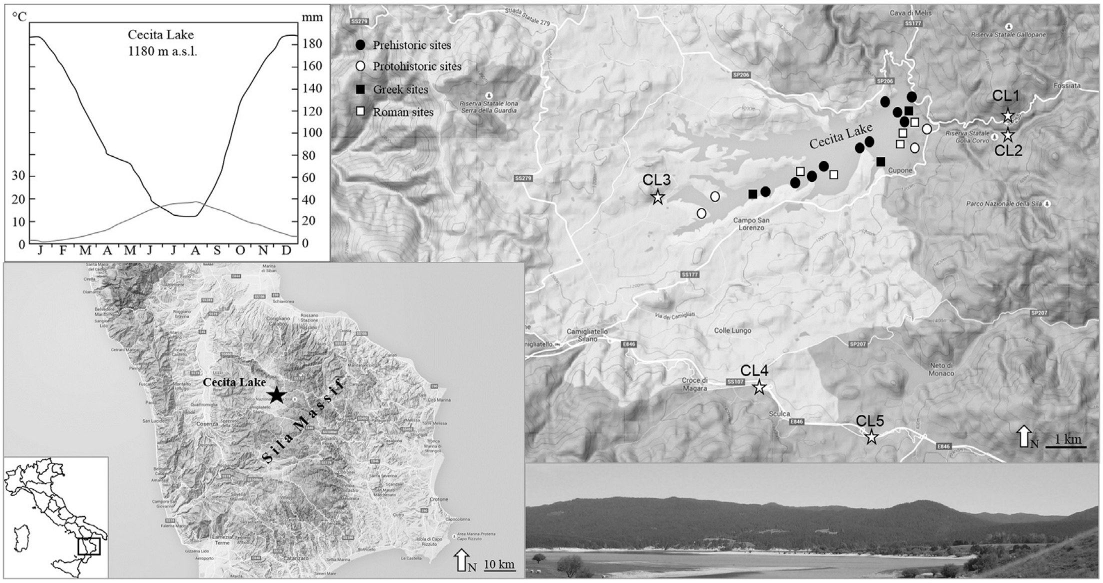


Fig. 1. Cecita Lake. Location map showing the area of Cecita Lake with the documented archaeological sites (black dot: Prehistoric site; white dot: Protohistoric site; black square: Greek site; white square: Roman site) and the excavated soil profiles (indicated with a star). On the links, the climatic diagram from the Cecita Lake weather station is shown.

Lombard territories was located across the Sila (for an overview of the cultural periods in Calabria, see Table 1).

3. Material and methods

3.1. Field works and laboratory treatments

Five representative soil profiles were selected in different locations in an area of ca. 40 km^2 south and east to the lake (Fig. 1), on the basis of (i) the pedostratigraphic position of the above-mentioned "Cecita Lake geosol" pointing to late Pleistocene/Holocene soil ages, (ii) the pedological spatial variability assessed from previous studies and (iii) the varying geomorphological contexts, i.e. river terraces (CL1: 39° 23′ 19″ N, 6° 34′ 14.1″ E; CL2: 39° 23′ 16.9″ N, 16° 34′ 13.1″ E), slopes (CL4: 39° 19′ 38.1″ N, 16° 29′ 53.8″ E) and transitional landforms where slope and/or fluvial deposits overlie terraced river sediments (CL3: 39° 37′ 01″ N, 16° 46′ 53″ E and CL5: 39° 18′ 55.8″ N, 16° 31′ 50.3″ N, respectively). The

Table 1
Calabrian cultural periods with the indication of the abbreviations used in Figs. 8 and 10 and the covered chronological frames expressed in years BP and years BCE/CE.

Cultural period	Abbreviation	Chronological frame (BP)	Chronological frame (BCE/CE)
Palaeolithic (Epigravettian)		19950–9950	18000-8000 BCE
Mesolithic		9950–7800	8000-5850 BCE
Early Neolithic	EN	7800–7500	5850-5550 BCE
Middle Neolithic	MN	7500–6150	5500-4200 BCE
Late Neolithic	LN	6150–5650	4200-3700 BCE
Early Eneolithic	EE	5650–5250	3700-3300 BCE
Middle Eneolithic	ME	5250–4750	3300-2800 BCE
Late Eneolithic	LE	4750–4150	2800-2200 BCE
Early Bronze Age	EBA	4150–3600	2200-1650 BCE
Middle Bronze Age	MBA	3600–3300	1650-1350 BCE
Recent Bronze Age	RBA	3300–3150	1350-1200 BCE
Final Bronze Age	FBA	3150–2950	1200-1000 BCE
Iron Age	IA	2950–2750	1000-800 BCE
Greek Age	GA	2750–2150	800-200 BCE
(Bruttian period)		(2350–2159)	*(400-200 BCE)*
Roman Age	RA	2150–1650	200 BCE - 300 CE
Late Antiquity	LA	1650–1350	300-600 CE
Early Middle Ages	EMA	1350–950	600-1000 CE
(Lombard/Byzantine period)			*(571-1060 CE)*
(Normann period)			*(1060-1194 CE)*
Late Middle Age	LMA	950–450	1000-1500 CE
(Swabian period)			*(1194-1266 CE)*
(House of Anjou domain)			*(1266-1283 CE)*
(Conflicts with the Crown of Aragon)			*(1283-1503 CE)*
Modern times	MT	450-present	1500 CE -present
(Spanish domain)			*(1503-1707 CE)*
(House of Habsburg domain)			*(1707-1735 CE)*
(Bourbons domain)			*(1735-1861 CE)*
(French regimes)			*(1805-1815 CE)*
(Italian unification)			*(1861 CE)*

vegetation cover is characterised by mature *Pinus laricio* forest with young trees of *Quercus cerris* and *Fagus sylvatica* at soil profiles CL1 and CL2, by open grassland with *Cytisus scoparius* shrublands and trees of *Alnus glutinosa* and *Populus nigra* along a nearby river at CL3; by open grassland with sparse trees of *Pinus laricio* and trees of *Alnus glutinosa* along the river at CL5. CL4 is located at the edge of a *Pinus laricio* forest. The study sites range in altitude between 1150 and 1363 m a.s.l. Four of the soil profiles (CL1, CL3, CL4 and CL5) were directly obtained from exposed slope cuts, while CL2 consists in a pit ca. 1 m long per 1 m wide dug in the soil 55 cm downward. Samples collection and laboratory treatments followed the standard procedure of the pedoanthracological method (Carcaillet and Thinon, 1996; Talon, 2010). A horizon-wise sampling strategy was applied (Pelle et al., 2013a, 2013b) in addition to a mere depth-based approach, as a basis for a deeper comprehension of vertical charcoal distribution in response to pedogenetic and/or morphodynamic processes. The volume of the collected samples ranges from 1.4 to 6.1 L of sediment. The samples were firstly air-dried and weighted. Then, they were wet-sieved through two sieves with 1 and 0.4 mm mesh-size. Charcoal concentration and taxonomical identification were performed for assemblages of charcoal pieces greater than 1 mm. Smaller charcoal pieces were excluded: since they were not taxonomically identifiable, they barely provide information on past forest composition (Robin et al., 2014). Charcoal concentration is expressed as specific anthracomass (SA) in milligrams of charcoal per kilogram of dried soil (Talon, 2010). Specific anthracomass is calculated per soil profile (SAP) and per sample layer (SAL).

Taxonomical identification was performed using an incident light microscope at magnifications of 100×, 200× and 500× and consulting wood anatomy atlases (Greguss, 1955, 1959; Schweingruber, 1990) and the reference collection of the paleoecology working group at the Institute for Ecosystem Research, University of Kiel. When the charcoal quantity allowed, taxonomical identification was done for 50 charcoal pieces per layer of sampling. It was generally possible to identify the charcoal fragments at the species or genus level; nevertheless, sometimes the bad conditions of preservation or vitrification events only allowed the identification at a family level or the solely distinction between coniferous, dicotyledon and monocotyledon wood or even prevented any identification.

From two layers of the soil profile CL5 (layers 3 and 4, corresponding to Ab and C horizons, respectively), samples were collected for pollen analysis. The samples were lab-treated according to standard procedures and counted (Faegri and Iversen, 1989; Moore et al., 1991).

3.2. Dating strategy

Among the identified charcoals, 32 samples were selected for AMS radiocarbon dating aiming at providing information about soil stratigraphy, the age of the identified charcoals and, consequently, the history of the most important identified taxa. For each soil profile, the charcoal pieces for radiocarbon dating were first selected based on their taxonomical interest and their location (i.e. soil horizon), also in relation to the spectrum of identified taxa in each layer. Then, their size and conservation state were taken into account to supply an adequate quantity of carbon for dating. AMS radiocarbon dating was finally performed on 7 charcoal pieces from CL1, 5 from CL2, 4 from CL3 and CL4, respectively, and 12 from CL5.

31 dates were obtained each one from a single charcoal fragment, while for 1 date of CL3 (horizon Bw_3), it was necessary to gather 5 charcoal pieces (from the same layer and the same taxon, *Juniperus*) to obtain a sufficient quantity of carbon for dating (1–2 mg of carbon, normally present in ≥10–20 mg of charcoal).

The AMS radiocarbon measurements were done at the Leibniz-Laboratory for Radiometric Dating and Isotope Research (Kiel, Germany), the Beta Analytic Laboratory (Miami, USA) and the Poznan Radiocarbon Laboratory (Poznan, Poland). The radiocarbon dates were calibrated using the Oxcal program, version 4.2 (Bronk Ramsey, 2009), based on the Intcal13 calibration curve (Reimer et al., 2013) and with a 2σ confidence interval (95% probability).

4. Results

4.1. Soil charcoal analysis

A total of 94 L of soil was sampled from the five soil profiles with ca. 32 g of extracted charcoal. To get taxonomical information, 1114 charcoal pieces were analysed allowing the identification of 16 taxa. Among the identified taxa, *Pinus* group *sylvestris* is the most attested (41%), followed by dec. *Quercus* and cf. dec. *Quercus* (18%), *Juniperus* (18%), *Abies alba* and cf. *Abies alba* (14%), Leguminosae (6%), *Fagus sylvatica* (1%), *Populus* and *Populus*/*Salix* (1%), unidentifiable monocotyledons (1%), *Acer*, *Alnus*, *Cornus*, cf. *Fraxinus*, cf. *Ostrya*/*Carpinus*, *Prunus*, *Sambucus* and Rosaceae/Maloideae (all < 1%). In 1% of the cases, it was not possible to distinguish between *Abies alba* and *Juniperus*. Unidentifiable dicotyledons and conifers constitutes 1% and 11% of the total analysed charcoals, respectively and unidentifiable charcoals (because of bad preservation status or vitrification) constitute 14% of the total. The results of the taxonomical identification, together with the SAP and SAL and the radiocarbon dating are presented for each soil profile in Figs. 2–6. In the anthracodiagrams presented in these figures, as well as in the Discussion, only the main identified taxa (*Abies alba*, *Fagus sylvatica*, *Juniperus*, dec. *Quercus*, *Pinus* group *sylvestris* and Leguminosae) are presented in detail. The other identified broadleaves are grouped under the definition “Other broadleaves”. *Abies*/*Juniperus*, the monocotyledons, the unidentifiable dicotyledons and conifers, and the unidentifiable charcoals are excluded from both the diagrams and the Discussion, but included in the SAP and SAL, since they provide information about the fire history. Concerning *Pinus* group *sylvestris*, although wood anatomy does not allow to distinguish between the different species *P. sylvestris*, *P. mugo* and *P. nigra* (Schweingruber, 1990), *P. sylvestris* and *P. mugo* can be ruled out because they do not grow in this region (Pignatti, 1982). Thus, we can reliably attribute our charcoals to *Pinus laricio*, a subspecies of *P. nigra*, which is an endemic and widespread tree in the mountain vegetation of Calabria between 800 and 1800 m a.s.l. (Pignatti, 1982).

In the figures, calculations and percentages are based on the charcoal frequencies (number of identified charcoal pieces per sample). The results of pollen analysis are shown in Fig. 7.

4.2. Radiocarbon dating

The results of radiocarbon dating are presented in Table 2. Sometimes, the radiocarbon dating of a single charcoal piece gave different possible dates. In these cases, the date with the smaller uncertainty range was chosen for the data interpretation. When the uncertainty range was identical, the date was selected on the base of other radiocarbon dates available for the same horizon or for the same taxon or it was just randomly chosen. In the discussion, all the reported dates are intended as calibrated BP (if not differently specified).

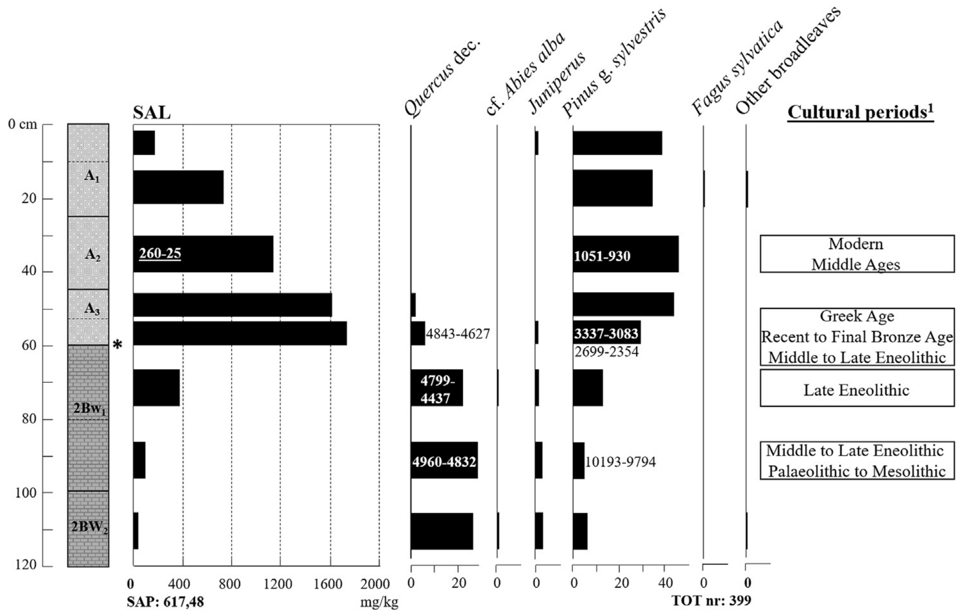


Fig. 2. Soil profile CL1. From the left to the right, the depth of the soil profile with the pedological horizons, the value of SAL and SAP, the diagram of the most important taxa identified with indication of the AMS radiocarbon dates and the documented cultural periods are presented. [1]The cultural periods are based on the radiocarbon dates of one or more charcoal pieces extracted from the pedological horizon/sediment sample. *: evidence of erosion/truncation; 260-25: radiocarbon date from previous studies (Scarciglia et al., 2008), the taxon of the dated charcoal is unknown.

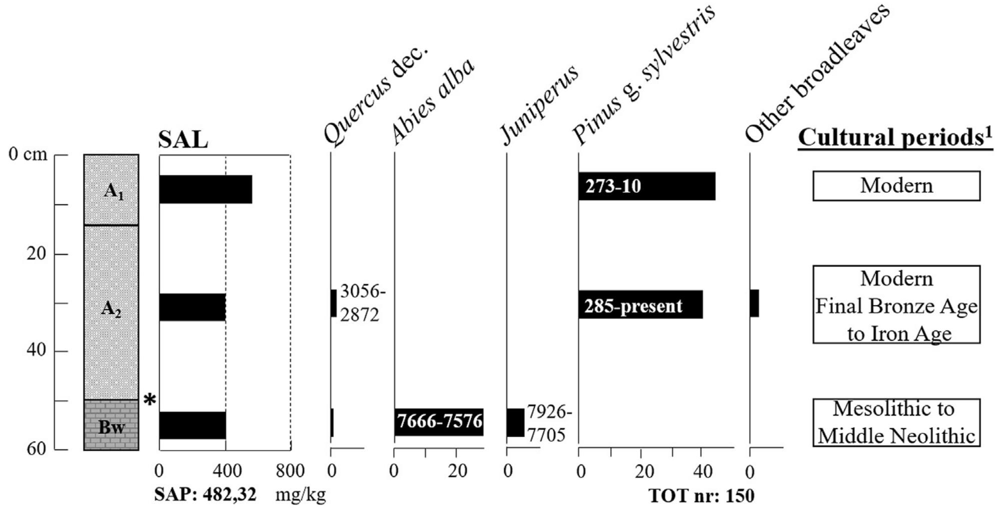


Fig. 3. Soil profile CL2. From the left to the right, the depth of the soil profile with the pedological horizons, the value of SAL and SAP, the diagram of the most important taxa identified with indication of the AMS radiocarbon dates and the documented cultural periods are presented. [1]The cultural periods are based on the radiocarbon dates of one or more charcoal pieces extracted from the pedological horizon/sediment sample. *: evidence of erosion/truncation.

5. Discussion

5.1. Taphonomical processes, charcoal concentration and stratification

Charcoal fragments present in soils are the result of the incomplete combustion of vegetation fuel (Forbes et al., 2006). It is difficult to establish the source and the formation processes leading to the creation of the charcoal assemblage. The main source are generally forest fires naturally ignited or fired by humans in relation to anthropogenic activities (Pyne and Goldammer, 1997; Moore, 2000; Bal et al., 2010). The possible provenance of charcoals from nearby human-related contexts, such as archaeological sites, charcoal kilns (charcoal production sites: Nelle, 2003) or temporary campfires has also to be taken into account when interpreting the charcoal record. Duration and intensity of the fire, as well as the type of burning vegetation are also influencing the final charcoal mass (Fréjaville et al., 2013). In case of forest burning, weather and topographic conditions can influence the dispersion and deposition of charcoal during and after the fire (Clark, 1988; Thinon, 1992; Scott et al., 2000). Anyway, charcoal particles larger than 0.5 mm are normally not transported more than a few meters from the burning area (Clark and Patterson, 1997; Ohlson and Tryterud, 2000), giving information about the fire-affected woody vegetation and its evolution with a high spatial resolution (Carcaillet and Thinon, 1996). In our case, the location of the soil

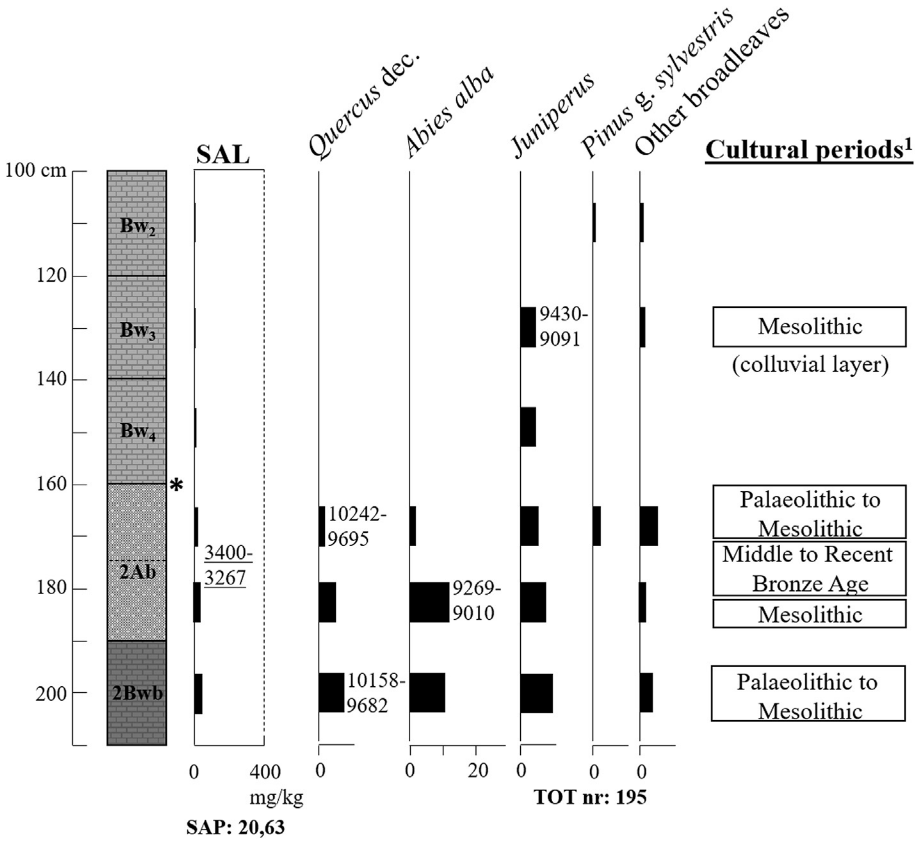


Fig. 4. Soil profile CL3. From the left to the right, the depth of the soil profile with the pedological horizons, the value of SAL and SAP, the diagram of the most important taxa identified with indication of the AMS radiocarbon dates and the documented cultural periods are presented. [1]The cultural periods are based on the radiocarbon dates of one or more charcoal pieces extracted from the pedological horizon/sediment sample. *: evidence of erosion/truncation; 3400-3267: radiocarbon date from previous studies (Scarciglia et al., 2008), the taxon of the dated charcoal is unknown.

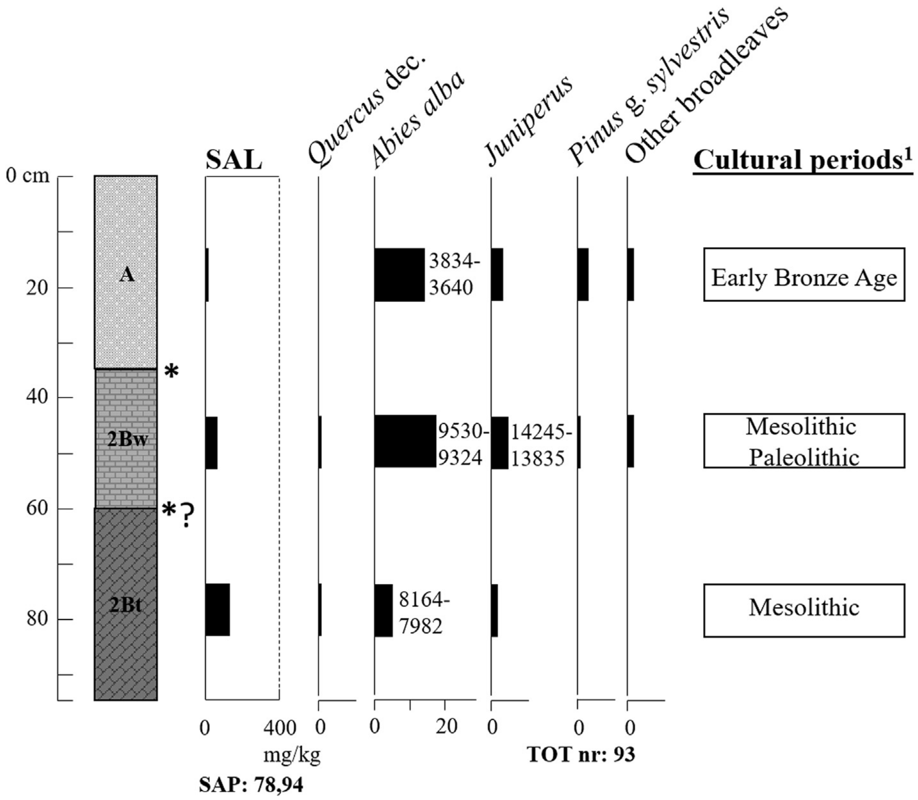


Fig. 5. Soil profile CL4. From the left to the right, the depth of the soil profile with the pedological horizons, the value of SAL and SAP, the diagram of the most important taxa identified with indication of the AMS radiocarbon dates and the documented cultural periods are presented. [1]The cultural periods are based on the radiocarbon dates of one or more charcoal pieces extracted from the pedological horizon/sediment sample. *: evidence of erosion/truncation, *?: possible evidence of erosion/truncation.

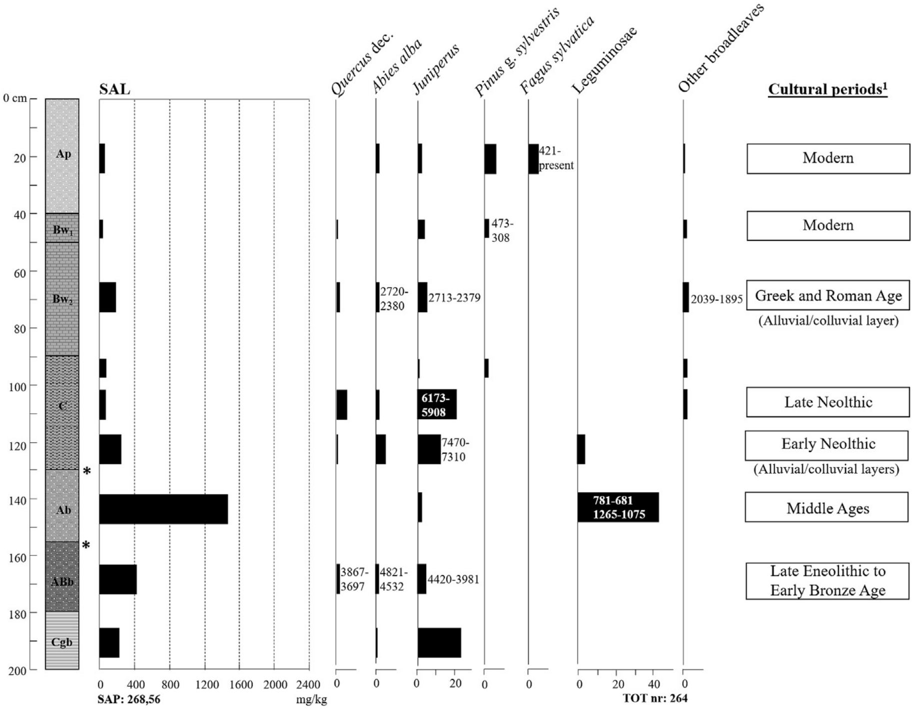


Fig. 6. Soil profile CL5. From the left to the right, the depth of the soil profile with the pedological horizons, the value of SAL and SAP, the diagram of the most important taxa identified with indication of the AMS radiocarbon dates and the documented cultural periods are presented. ^{1}The cultural periods are based on the radiocarbon dates of one or more charcoal pieces extracted from the pedological horizon/sediment sample. *: evidence of erosion/truncation.

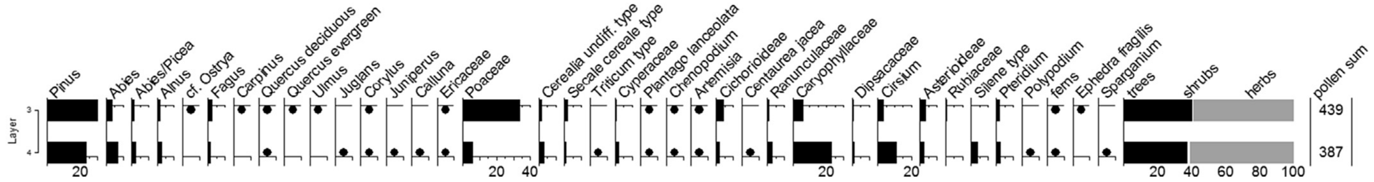


Fig. 7. Pollen records from soil profile CL5. In the diagram, the results of pollen analysis from layers 3 and 4 (corresponding to Ab and C horizons, respectively) are presented. Percentages are based on land pollen sum (analysis: Y. Dannath, O. Nelle).

profiles on flat (such as CL2) to gently-inclined relief (CL1) or at the foot of small slopes (CL3, CL4 and CL5) and the selection of charcoals ≥ 1 mm for the taxonomical identification allow us to consider the charcoal assemblage as being formed almost locally. Soil profile CL5 is located along a river terrace, opening the possibility of the transport of charcoal by water from farther distances, nevertheless the pedological analysis permitted to clearly distinguish *in situ*-formed horizons from alluvial deposits. Moreover, the absence of archaeological features, charcoal kilns or other human structures near the soil profiles drives us to consider with high probability our charcoal as the result of natural or anthropogenic woodland fires.

After the fire, different processes of perturbation may affect the soil, leading to the dislocation of the charcoals at different soil depths and to their fragmentation. Pedoturbation, bioturbation and uprooting processes contribute to the mixing of the charcoal pieces in the soil; therefore, the soil charcoal vertical distribution is often not chronologically ranged (Carcaillet, 2001; Gavin et al., 2003; Robin et al., 2012). Nevertheless, the large number of radiocarbon dating and the pedological field features of the soil profiles permitted to control the age/depth relation of the charcoals. Moreover, despite phenomena of inversion in the relationship between the age of charcoal and the depth of the sample (as in CL5) or the contemporary presence of charcoals with different ages in the same sample (as in CL1 and CL2), a clear pattern of Holocene vegetation change – the transition from a deciduous oak and silver fir forest to a pine forest – is visible along the depth of almost all the investigated soil profiles.

5.2. Fire events and vegetation changes at Cecita Lake

The low number of sampled soil profiles and the sole analysis of macro-charcoals prevent us from reconstructing the fire history of the area: our record provides us with a local and discontinuous signal of fires. In fact, the association of soil charcoals with macro- and micro-charcoals from mires or lake deposits is necessary to obtain profound data (e.g. Robin et al., 2013). Bearing in mind this limitation, it is anyway possible to note first a higher concentration of dates in the second part of the Holocene and then the presence of periods characterised by a higher number of date ranges in our record (Fig. 8a). Radiocarbon ages are concentrated around 10400-9000 BP, 8200-7200 BP, 5100-3700 BP, 3300-2400 BP and 600 BP to the present. For the period 5100-3700 BP, radiocarbon ages are particularly concentrated at 5100-4500 and 3800 BP. Assuming that the charcoal record is a result of forest fires, we can argue that these concentrations of radiocarbon dating mirror periods of increased

Table 2
Radiocarbon dates.

Soil profile	Pedological horizon	Laboratory reference	Radiocarbon date	Calibrated age at 2σ interval	Taxon
CL1	A_2	KIA45420	1065 ± 25 BP	1051-930 cal. BP	*Pinus* group *sylvestris*
CL1	A_3	KIA45421	4200 ± 30 BP	4843-4627 cal. BP	deciduous *Quercus*
CL1	A_3	KIA47441(1)	2430 ± 30 BP	2699-2354 cal. BP	*Pinus* group *sylvestris*
		KIA47441(2)	2695 ± 30 BP	2850-2755 cal. BP	
CL1	A_3	KIA50234(1)	3000 ± 40 BP	3316-3080 cal. BP	*Pinus* group *sylvestris*
		KIA50234(2)	3020 ± 25 BP	3337-3083 cal. BP	
CL1	$2Bw_1$	KIA48518	4065 ± 30 BP	4799-4437 cal. BP	deciduous *Quercus*
CL1	$2Bw_1$	KIA48519(1)	4305 ± 25 BP	4960-4832 cal. BP	deciduous *Quercus*
		KIA48519(2)	4355 ± 30 BP	5032-4851 cal. BP	
CL1	$2Bw_1$	KIA48520	8895 ± 45 BP	10193-9794 cal. BP	*Pinus* group *sylvestris*
CL2	A1	POZ-59596	125 ± 30 BP	273-10 cal. BP	*Pinus* group *sylvestris*
CL2	A2	POZ-59597	155 ± 30 BP	285 cal. BP -present	*Pinus* group *sylvestris*
CL2	A2	KIA48512	2845 ± 25 BP	3056-2872 cal. BP	deciduous *Quercus*
CL2	Bw	KIA48513(1)	6760 ± 30 BP	7666-7576 cal. BP	*Abies*
		KIA48513(2)	6675 ± 30 BP	7591-7489 cal. BP	
CL2	Bw	KIA48514	6975 ± 35 BP	7926-7705 cal. BP	*Juniperus*
CL3	Bw3	POZ-59598	8270 ± 50 BP	9430-9091 cal. BP	*Juniperus*
CL3	2Ab	KIA48516	8170 ± 50 BP	9269-9010 cal. BP	*Abies*
CL3	2Ab	KIA48515	8920 ± 100 BP	10242-9695 cal. BP	deciduous *Quercus*
CL3	2Bwb	KIA48517	8820 ± 55 BP	10158-9682 cal. BP	deciduous *Quercus*
CL4	A	KIA48507	3465 ± 35 BP	3834-3640 cal. BP	*Abies*
CL4	2Bw	KIA48508(1)	8430 ± 40 BP	9530-9324 cal. BP	*Abies*
		KIA48508(2)	8525 ± 50 BP	9554-9453 cal. BP	
CL4	2Bw	KIA48509	12180 ± 60 BP	14245-13835 cal. BP	*Juniperus*
CL4	2Bt	KIA48510	7245 ± 36 BP	8164-7982 cal. BP	*Abies*
CL5	Ap	POZ-59591	230 ± 30 BP	421 cal. BP -present	*Fagus sylvatica*
CL5	Bw1	POZ-59592	330 ± 30 BP	473-308 cal. BP	*Pinus* group *sylvestris*
CL5	Bw2	KIA48050	2015 ± 25 BP	2039–1895 cal. BP	*Cornus*
CL5	Bw2	KIA48051(1)	2865 ± 30 BP	3072-2879 cal. BP	*Juniperus*
		KIA48051(2)	2740 ± 30 BP	2920-2765 cal. BP	
		KIA48051(3)	2465 ± 30 BP	2713-2379 cal. BP	
		KIA48051(4)	2805 ± 30 BP	2995-2804 cal. BP	
CL5	Bw2	POZ-59593	2475 ± 30 BP	2720-2380 cal. BP	*Abies*
CL5	C	POZ-59595	5215 ± 35 BP	6173-5908 cal. BP	*Juniperus*
CL5	C	BETA-320186	6480 ± 40 BP	7470-7310 cal. BP	*Juniperus*
CL5	Ab	BETA-320187	810 ± 30 BP	781-681 cal. BP	Leguminosae
CL5	Ab	KIA48052(1)	1250 ± 25 BP	1273-1084 cal. BP	Leguminosae
		KIA48052(2)	1240 ± 25 BP	1265-1075 cal. BP	
CL5	ABb	BETA-320188	4130 ± 30 BP	4821-4532 cal. BP	*Abies*
CL5	ABb	KIA48053(1)	3510 ± 30 BP	3867-3697 cal. BP	deciduous *Quercus*
		KIA48053(2)	3455 ± 30 BP	3828-3640 cal. BP	
CL5	ABb	KIA48054	3810 ± 80 BP	4420-3981 cal. BP	*Juniperus*

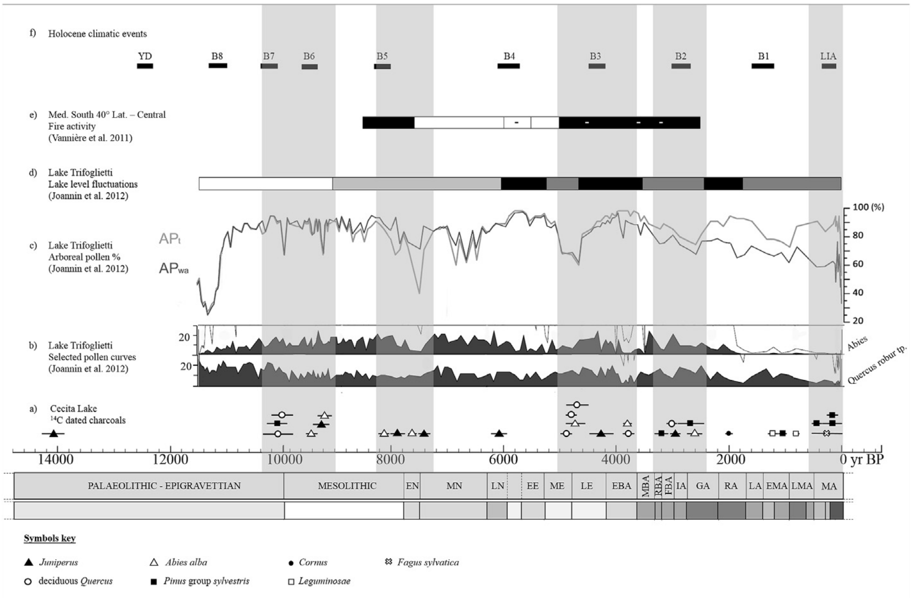
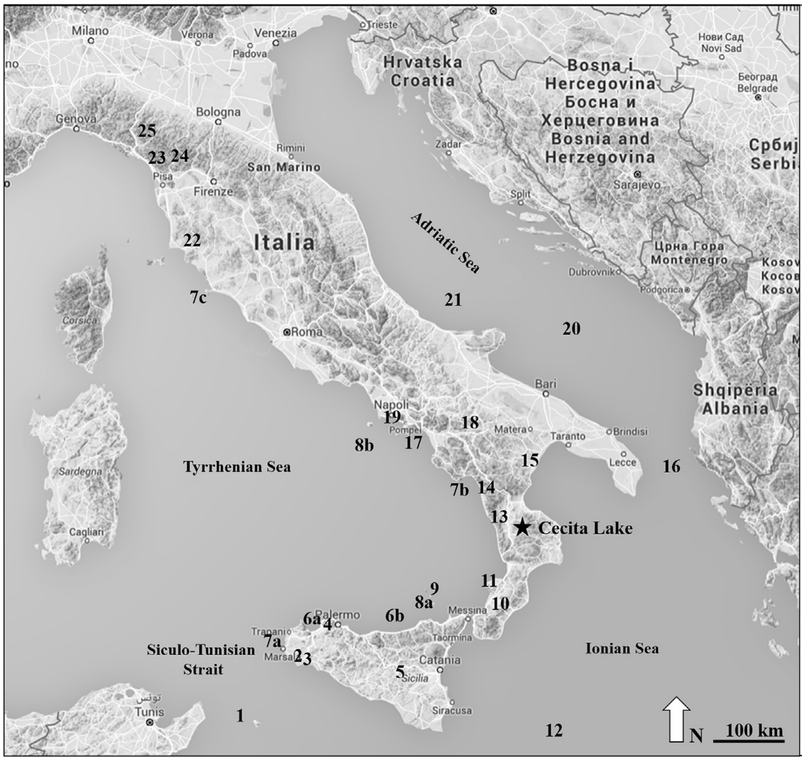


Fig. 8. Proxy data from the region. A comparison is proposed between the concentrations of radiocarbon ages at Cecita Lake, selected pollen curves and lake level fluctuations from Lake Trifoglietti and the fire activity recorded in southern Italy. In d) and e) black indicates low lake level – high fire activity, grey indicates intermediate lake level; white indicates high lake level – low fire activity. The most important Holocene climatic events are indicated: YD Younger Dryas; B Bond events; LIA Little Ice Age. On the bottom, the cultural periods are listed (for Abbreviations see Table 1), together with the settlement dynamics (light grey: low population density, dark grey: high population density).



Nr.	Site name	Reference
1.	Core MD04-2797CQ	Desprat et al., 2013 Bout-Roumazeilles et al., 2013
2.	Lake Preola	Magny et al., 2011
3.	Gorgo Basso	Tinner et al., 2009
4.	Caraburangeli Cave	Frisia et al., 2006
5.	Pergusa Lake	Sadori and Giardini, 2007; Sadori and Narcisi, 2001; Sadori et al., 2013
6a, 6b.	Cores BS79-38 and BS79-33	Cacho et al., 2001
7a, 7b, 7c	Tyrrhenian spelean serpulids	Antonioli et al., 2001
8a, 8b.	Cores KET80-03 and KET80-19	Kallel et al., 1997
9.	Aeolian Islands	Caracuta et al., 2012
10.	Cànolo Nuovo	Schneider, 1985
11.	Punta Zambrone	D'Auria et al., accepted
12.	Core RL11	Emeis et al., 2000
13.	Lake Trifoglietti	Joannin et al., 2012
14.	Santuario della Madonna Cave	Scarciglia et al., 2009
15.	Bradano valley	Piccarreta et al., 2011
16.	Core AD91-17	Sangiorgi et al., 2003
17.	Salerno Bay	Russo Ermolli and Di Pasquale, 2002 Di Donato et al., 2008
18.	Monticchio Lake	Allen et al., 2002
19.	Naples coastline	Romano et al., 2013
20.	Core MD90-917	Combourieu-Nebout et al., 2013; Siani et al., 2013
21.	Core RF93-30	Oldfield et al., 2003; Mercuri et al., 2012
22.	Accesa Lake	Drescher-Schneider et al., 2007; Magny et al., 2007; Vannière et al., 2008
23.	Corchia Cave	Zanchetta et al., 2007
24.	Greppo Lake	Vescovi et al., 2010
25.	Prato Spilla	Lowe et al., 1994

Fig. 9. Selected proxy records from Italy. Location map and references of the most important sites cited in the text.

fire activity. Moreover, the comparison of our data with the fire activity in the region ("central Mediterranean region south of 40° Lat." by Vannière et al., 2011) shows a high conformity of the fire signal (Fig. 8e): this fact well integrates our data in the regional picture. The large timeframe covered by the dated charcoals allows us to draw a first detailed history of the vegetation changes in the Sila Massif uplands.

5.2.1. *The Late Glacial: steppe-like environment with juniper*

The older dated charcoal of our record dates back to the Late Glacial around 14000 BP. The identification of the charcoal as *Juniperus* (most probably *J. communis*, based on its ecological characters and its present distribution in Italy: Pignatti, 1982) seems to indicate that the area was characterised by a mostly open environment with the presence of shrublands with juniper. This picture seems to be confirmed by the almost exclusive finding of juniper charcoal in the lower level of CL5, which likely represents a Late Glacial soil. In fact, the light grey colour of its pedogenic matrix, overprinted by yellow (and occasionally yellowish-red) mottles, indicate the dominance of reduced iron forms and Fe-hydroxides (goethite) rather than oxides (hematite), favoured by cool and humid climates (Torrent et al., 1980; Schwertmann and Taylor, 1989). These features point to prevalent reductimorphic conditions under stagnating water caused by partially impeded drainage, in turn promoted by the high clay content of this soil horizon. This behaviour could have been favoured by low temperatures and possibly slow ice melting promoting prolonged water availability during cold glacial periods (Scarciglia et al., 2003, 2006). Moreover, it well agrees with the available pollen records from central and southern Italy (for the location of the sites quoted here and in the other sections of the paper, see Fig. 9), which document the expansion of arboreal taxa only in a later stage. In fact, a "steppe-like" environment during the Late Glacial is documented also in other mountainous areas of Italy: at the nearby Lake Trifoglietti (Joannin et al., 2012) and at Cànolo Nuovo on the Serre mountains in southern Calabria (Schneider, 1985) and at Monticchio Lake in the southern Apennines (Allen et al., 2002).

5.2.2. *The Early Holocene: establishment of a mixed deciduous oak-silver fir forest*

The first concentration of radiocarbon dates is recorded at 10400-9000 BP. Taxonomical identifications document the presence of deciduous *Quercus*, *Abies alba* and, in a lesser extent, *Juniperus* and *Pinus* group *sylvestris*. Charcoals testify that in this period a mixed deciduous oak-silver fir forest is already established (see the lower levels of CL3, Fig. 4). This date fits in the time of reforestation of other Italian mountain areas at the Late Glacial-Early Holocene transition, as testified by pollen records (e.g. Vescovi et al., 2010; Joannin et al., 2012). At Cecita Lake, this vegetation cover will constitute the main forest type until the Early Bronze Age. It is noteworthy to mention the presence of silver fir. In fact, the mixed mesophilous deciduous forest with silver fir seems to represent the typical woodland of the Italian Apennines during the Early and Middle Holocene at both mid and low elevations (Di Pasquale et al., 2014), as testified by numerous pollen records (e.g. Schneider, 1985; Allen et al., 2002; Russo Ermolli and Di Pasquale, 2002; Oldfield et al., 2003; Di Donato et al., 2008; Joannin et al., 2012; Mercuri et al., 2012). In the northern Apennines, silver fir is abundant in association with mesophilous deciduous trees or even with Mediterranean taxa such as *Quercus ilex* (Lowe et al., 1994; Colombaroli et al., 2007; Drescher-Schneider et al., 2007; Kaltenrieder et al., 2010) and it is subjected to a strong decline, induced by excessive anthropogenic disturbance, since ca. 5000 years ago (Tinner et al., 2013). The late persistency of silver fir in the area of Cecita Lake (see Section 5.2.5) confirms its later decline, due to human overexploitation, in southern Italy, as documented by pollen and charcoal data (Di Pasquale et al., 2014; for the Sila upland, see also Ferrarini, 1978).

Magny et al. (2013), in a review based on different paleohydrological records, argue for an Early to Middle Holocene characterised in southern Italy by generally wet conditions, which did last from 10500 until 4500 BP, although oscillations between dry/wet conditions characterised the first phase from ca. 10500 to 9000 BP (Magny et al., 2012). Increasing moisture in the early Holocene is documented also by other multi-proxies records from southern Italy (Tinner et al., 2009; Combourieu-Nebout et al., 2013; Desprat et al., 2013). This general wetter climate seems to run counter a natural origin of the fires in this period. Despite this, high fire activity is registered also in Sicily at Lake Pergusa (Sadori and Giardini, 2007) and at Gorgo Basso (Tinner et al., 2009) and two drops in arboreal pollen percentage are recorded at Lake Trifoglietti at ca. 9800 and 9200 BP (Fig. 8c; Joannin et al., 2012). The high fire activity could be due to dry episodes connected to Bond events 7 and 6 (Bond et al., 2001). In fact, dry/cold episodes are observed in this period in the central Mediterranean (Cacho et al., 2001; Desprat et al., 2013). Moreover, a sharp seasonal contrast is documented at the beginning of the Holocene in southern and central Italy (Frisia et al., 2006; Vannière et al., 2008; Magny et al., 2011; Combourieu-Nebout et al., 2013). The sharper seasonal contrast, superimposed to possible dry episodes, could have led to a higher flammability of the woodlands, especially in association with the increase of biomass availability related to the reforestation process. Concerning a possible human influence on fire events, Bos and Urz (2003) highlight the impact – in term of woodland fires - of the early Mesolithic populations in central Germany. Early human impact is considered as possible cause of environmental changes also in the marsh environment of Jordan (Ramsey et al., 2015) and, in Italy, at Lake Accesa (Drescher-Schneider et al., 2007), at Prato Spilla (Lowe et al., 1994) and in the Salerno Bay (Russo Ermolli and Di Pasquale, 2002). During the period 10400-9000 BP is documented in Calabria the transition from the last Palaeolithic industry (Palma di Cesnola, 2004) to the Mesolithic one (Martini, 2004).

5.2.3. The onset of Neolithic and the 8.2 ka event: evidence of human impact or climate change?

The second group of radiocarbon dates is found between 8200 and 7200 BP. The taxonomical identification of the dated charcoals documents the presence of *Abies alba* and *Juniperus*. The persistency of deciduous *Quercus* is attested by charcoal findings at the archaeological sites located along the shores of Cecita Lake and dated to the Late Neolithic (Pelle et al., 2013a, b) and by the charcoal assemblages of the lower levels of soil profiles CL2 and CL4, where silver fir and deciduous oak coexist together with juniper (Figs. 3 and 5).

From a climatic point of view, this period falls into the so-called “Holocene climatic optimum” corresponding to the deposition of Sapropel 1 in the eastern part of the Mediterranean Basin between ca. 9500 and 6500 BP (Rohling, 1994; Rossignol-Strick, 1999). In southern Italy, paleohydrological proxies document prevalent wet conditions, with enhanced rainfall both in winter and in summer (Magny et al., 2012, 2013). Enhanced rainfalls are attested also by studies on marine proxies from the central Mediterranean (Bout-Roumazzeilies et al., 2013), in association with warm (Emeis et al., 2000; Sangiorgi et al., 2003; Siani et al., 2013) or cool conditions (Kallel et al., 1997; Antonioli et al., 2001; Cacho et al., 2001). In north-western Calabria, geoarchaeological analysis depict for the Late Neolithic a relative geomorphological stability under a humid and seasonally contrasted climate (Scarciglia et al., 2009). In the frame of this general wet climate, cool/cold spells are identified in the southern Adriatic Sea (Siani et al., 2013). Cold and dry episodes are documented also in Sicily by the speleothem record at Carburangeli Cave (Fig. 10b; Frisia et al., 2006) and by lake level fluctuations at Lake Preola (Fig. 10d; Magny et al., 2011). No prominent cold and/or dry events are, instead, observed for this period in central Italy, where speleothem record from Corchia Cave (Fig. 10g; Zanchetta et al., 2007) and low lake level at Lake Accesa (Fig. 10h; Magny et al., 2007) seem to show a pattern of wet winters and dry summers (Magny et al., 2013). Some of the above-mentioned cold and/or dry spells, centred around 8200 BP, likely correspond to the important 8.2 ka event detected in many climatic records of the Northern Hemisphere (Alley and Ágústsdóttir, 2005). In the central Mediterranean, this event seems to be not particularly prominent, since it is not always recognisable in proxy data. Pollen records available for this period show contrasting patterns of vegetation changes. In the mountainous areas of Italy, the period between 8200 and 7500 BP is characterised by a drop in *Abies* and *Fagus* pollen at Lake Trifoglietti (Fig. 8b and c; Joannin et al., 2012), while the forest is pretty stable at Cànolo Nuovo (Schneider, 1985) and at Monticchio Lake, where the period between 8100 and 3000 BP corresponds to the maximum expansion of *Abies* (Allen et al., 2002). More north on the Apennines, pollen record from Greppo Lake also documents a dense and stable forest between 9500 and 6000 BP (Vescovi et al., 2010), while at Prato Spilla woodland disturbance is recorded at ca. 8000 BP (Lowe et al., 1994). At the medium elevation site of Lake Pergusa, arboreal pollen minima are observed at 8100 and 7600 BP (Sadori and Narcisi, 2001). Similar contrasting conditions are documented also at low elevation areas, showing alternatively a stable and forested landscape (Giardini, 2007; Di Rita et al., 2013) or evidence of forest opening (Sadori et al., 2011). At Lake Accesa, high and regular fire activity is observed (Drescher-Schneider et al., 2007). Vannière et al. (2011) indicate, for the central Mediterranean south of 40° latitude, a high (but decreasing) fire activity until ca. 7500 BP and low fire activity during the middle Holocene until ca. 5000 BP (Fig. 8e).

The examined climate and vegetation data depict a context of different environmental changes not only among the regions of the Mediterranean (as highlighted by Vannière et al., 2011; Magny et al., 2013) but also among sites in the same region. The concentration of radiocarbon dates in our record could be a local response to the 8.2 ka event. In fact, in the general warm and wet conditions of this period in this part of Italy, the persisting dominance of phyllosilicates vs. short-range order minerals (SROM) as weathering products of primary aluminosilicate components and the presence of degenerated clay coatings of illuvial origin in the soils around Cecita Lake (Pelle et al., 2013b), indicate some seasonal contrast and/or a superimposition of drying episodes. However, this period corresponds in Calabria to the Mesolithic-Neolithic transition, the *Neolithization* starting in the region about 7800 years ago (Marco Pacciarelli, personal communication). During the Neolithic time, Calabria was one of the most densely populated regions of Italy (Tiné, 1987) and archaeological data show existing contacts with Sicily and with peninsular Italy already during the Early and Middle Neolithic (Ammerman, 1979). The documented concentration of radiocarbon dates could reflect the impact of Neolithic populations in the area of Cecita Lake, which has a central importance with regard to the connecting routes between the south and the north of the region. The human impact on wooded landscape during the Mesolithic-Neolithic transition and the Early Neolithic is, in fact, documented by paleoecological data also in other areas of Europe (Innes et al., 2013; Warren et al., 2014; Albert and Innes, 2015) and Italy (Drescher-Schneider et al., 2007).

5.2.4. Middle Eneolithic to Early Bronze Age: from climate-driven to human-driven fire events

The next concentration of radiocarbon dates is found at ca. 5100-3700 PB and it is opening a period characterised by a quite high amount of dates lasting until nowadays. The almost complete absence of radiocarbon dates between 7200 and 5100 BP, and the

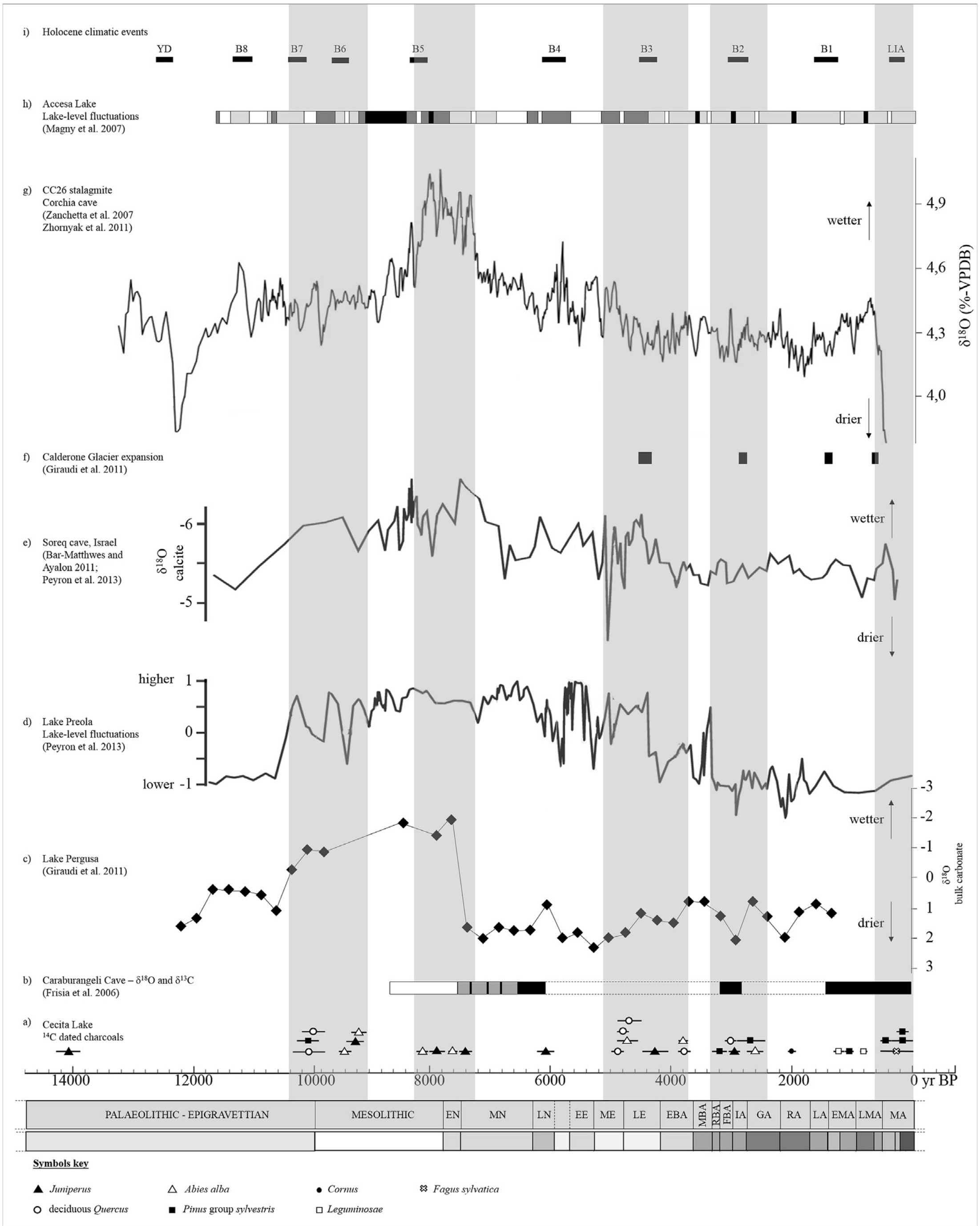


Fig. 10. Selected proxy data from Italy. A comparison is proposed between the concentrations of radiocarbon ages at Cecita Lake and different proxy data from southern and central Italy. In b) and h) black indicates dry conditions – low lake level, grey indicate intermediate lake level; white indicates high lake level – wet conditions. The most important Holocene climatic events are indicated: YD Younger Dryas; B Bond events; LIA Little Ice Age. On the bottom, the cultural periods are listed (for Abbreviations see Table 1), together with the settlement dynamics (light grey: low population density, dark grey: high population density).

new concentration after this date well agree with the data on fire activity observed by Vannière et al. (2011) in the region (Fig. 8e).

Taxonomical identification attests the presence of deciduous *Quercus*, *Abies alba* and, in a lesser extent, *Juniperus*. The persistency of the mixed deciduous oak-silver fir forest is documented at least until the Late Eneolithic in the $2Bw_1$ horizon of soil profile CL1 and at least until the Early Bronze Age in the upper horizon of CL4 and in the ABb horizon of CL5 (Figs. 2, 5 and 6).

The period around 5000-4000 BP seems to represent a turning point for the central Mediterranean, both from a climatic and a cultural point of view.

From a climatic point of view, Magny et al. (2011, 2013) and Peyron et al. (2013) argue that the period around 4500-4000 BP corresponds to a climate reversal in the central Mediterranean basin, which leads to the establishment of drier (wetter) summer conditions during the late Holocene south (north) of ca 40° N. As a result, after 4500 BP southern Italy seems to experience an increasing seasonal contrast with wet winters and dry summers

(Magny et al., 2012). An apparent complexity of the climate in this period seems to be documented in the whole Mediterranean (as highlighted also by Roberts et al., 2011), characterised by higher environmental variability (Giraudi et al., 2011; Giraudi, 2014) and successive dry/wet oscillations (Fig. 10e: Bar-Matthews and Ayalon, 2011; Carrión, 2002; Magny et al., 2009). Moreover, continental proxy data from central Italy show a local climatic evidence of the 4.2 ka event recorded in the North Atlantic (Bond et al., 2001), in the form of a dry and cold spell (Drysdale et al., 2006; Giraudi et al., 2011: Fig. 10f). In southern Italy, a trend toward increasing aridification is documented for this period in Sicily at Lake Pergusa (Fig. 10c; Sadori et al., 2008) and Lake Preola (Fig. 10d; Magny et al., 2011), as well as in the southern Tyrrhenian Sea (Kallel et al., 1997) and in the Siculo-Tunisian Strait (Bout-Roumazeilles et al., 2013). At Lake Trifoglietti a shift from intermediate deep water to shallower water is documented since 6000 BP, with an episode of deeper water at 5200-4300 and again shallower water at 4300-3500 BP suggesting drier summer conditions (Joannin et al., 2012). On the other hand, in the Bradano valley area north to Cecita Lake palaeoflood analysis indicates cool-wet episodes at 4800-4550 and 4300-4100 BP (Piccarreta et al., 2011) and along the Naples coast sedimentological data give evidence of climatic instability with high-intensity rainfall events during the Eneolithic (Romano et al., 2013). Geoarchaeological analysis at Santuario della Madonna Cave on the northern Tyrrhenian coast of Calabria shows during the Late Neolithic up to the Bronze Age an alternating pedostratigraphic record, indicating short-term climate changes with increasing aridity and seasonality, often coupled with heavy human disturbance (Scarciglia et al., 2009). In fact, in Italy this period corresponds to the development of the Eneolithic and, starting at ca. 4200 BP, of the Early Bronze Age populations, which show substantial changes with respect to the previous Neolithic groups. The archaeological data document the diffusion of common *facies* (i.e. common pottery features) attesting the existence of population contacts extended first in the southernmost part of Italy and then up to central Italy (Peroni, 1996; Pacciarelli, 2011). During the late Eneolithic, contributions from central Europe (Beaker culture) and especially from the Balkans (Četina facies) are also documented (Pacciarelli, 2011; Pacciarelli and Talamo, 2011), testifying the development of broader cultural networks. Moreover, the Eneolithic corresponds to the development and spread of metallurgy in the Italian peninsula (Carancini, 2004) and Calabria seems to play a central role in the diffusion of this technique in the central Mediterranean (Salerno and Vanzetti, 2004). The increasing population and social complexity have surely had an impact on the natural environment around the settlements. The complexity of the climatic and cultural scenario characterising the Italian peninsula in the mid part of the Holocene, makes it difficult to evaluate the respective importance of humans and climate in the observed environmental changes. Major episodes of forest reduction or the beginning of forest opening are documented by pollen records in many areas of the Italian peninsula in this period. The nearby pollen record from Lake Trifoglietti documents the beginning of forest regression at ca. 4000 BP and it is interpreted by the authors as the combined result of the mid-to late Holocene climate drying and the forest opening by Bronze Age populations (Fig. 8b and c; Joannin et al., 2012). Human impact is seen as the triggering factor in the forest decline also in other areas of southern (Noti et al., 2009) and central Italy (Lowe et al., 1994; Drescher-Schneider et al., 2007). Other scholars, instead, consider a climate deterioration the primary forcing of the vegetation change, combined with increasing human impact (Sadori et al., 2004; Caroli and Caldara, 2007; Di Rita and Magri, 2009; Sadori et al., 2013). Other pollen records, instead, do not show in this time significant changes in the forest cover, as at Gorgo Basso (Tinner et al., 2009) and Lake Preola (Magny et al., 2011) on the Sicilian coast and at Monticchio Lake in the inland southern Apennines (Allen et al., 2002).

Concerning the first concentration of radiocarbon dates in our record at ca. 5100-4500 BP, the above quoted prevalence of phyllosilicate clays over SROM components and the presence of degenerated clay coatings in the pedological horizons dated to this period indicate overall warm and humid climate conditions with some seasonal contrast, but possibly superimposed by drier phases, which can be consistent with increase of natural fire activity. At 3800 BP, the human activity likely is the triggering factor of the forest burning. In fact, during the Early Bronze Age, settlements are well documented along the shores of Cecita Lake and archaeological data testify the practicing of agriculture and mining (Marino and Pacciarelli, 1996; Marino and Taliano Grasso, 2010).

5.2.5. *Environmental change: the impact of Middle Bronze Age populations*

A new group of radiocarbon dates is centred at ca. 3300-2400 BP. Taxonomical identification documents the presence of *Pinus* group *sylvestris*, deciduous *Quercus*, *Juniperus* and *Abies alba*.

If we look at the soil profiles, significant changes in the vegetation cover can be seen. In CL1, the previous mixed deciduous oak-silver fir forest is substituted by a Calabrian pine woodland, which developed at least since the Recent Bronze Age (A_3 horizon; Fig. 2). A similar situation is visible in the nearby CL2, where a deciduous oak charcoal radiocarbon dates at the Final Bronze Age/Iron Age the A_2 horizon, in which the charcoal assemblage shows the almost exclusive presence of Calabrian pine (the younger charcoal of Calabrian pine found in the same horizon is probably transported down from the upper horizon through bioturbation/uprooting; Fig. 3). In CL3, the 2Ab horizon, where the mixed deciduous oak-silver fir forest is still present and the younger radiocarbon date refers to 3400-3267 BP, shows in its upper surface signs of erosion and it is followed by a considerable sedimentary aggradation, resulting in the deposition of a series of colluvial layers affected by early pedogenesis (Fig. 4). In CL4, the upper level, i.e. the A horizon, is dated to the Early Bronze Age and includes a prevalence of silver fir charcoals. This fact could be due to a mixing up of the charcoals caused by bioturbation or uprooting or by the transport of older material from the upper slope, as suggested by the irregular distribution of the charcoal dates in depth and by the topographic position. Also the lack of younger ages in the topsoil is consistent with the effects of morphodynamic processes and suggests that the soil profile was affected by surface erosion (Fig. 5).

Finally, in CL5 the ABb horizon, dated up to the Early Bronze Age and characterised by the presence of the deciduous oak-silver fir forest, is followed by a layer in which the charcoal assemblage is composed uniquely by small branches of Leguminosae, radiocarbon dated to the Middle Ages (Fig. 6). The limit between the two horizons shows clear evidence of erosion/truncation of the lower soil and burial by younger deposits and related soil. Pollen analysis shows for Ab and C horizons the dominance of non-arboreal pollen confirming the presence of an open landscape around the site during the formation time of the layers. Arboreal pollen are dominated by *Pinus*, with a significant presence of *Abies* and *Fagus* (Fig. 7). To sum up, in the period between the Middle Bronze Age and the Final Bronze Age/Iron Age (ca. 3600 to 3000 BP), the mixed deciduous oak-silver fir woodland declined and was substituted by a Calabrian pine forest or by an open landscape that, without the protection of the vegetation cover, underwent conditions of geomorphological instability characterised by events of surface runoff, erosion and subsequent sedimentary aggradation (Scarciglia et al., 2008; Pelle et al., 2013b).

In the Sila uplands, *Pinus laricio* forest is considered as a paraclimax vegetation representing a result of the degradation phase of the deciduous oak forest (Barbéro et al., 1998; Quézel and Médail, 2003). Being a light-demanding pioneer tree, it needs a period of open landscape to establish and, thus, it testifies a severe degradation of the environment around Cecita Lake after the Early Bronze Age. Moreover, the geomorphic instability of the area after the disruption of the mixed deciduous forest is well indicated also by the accumulation of different A horizons or of colluvial layers in the upper part of the investigated soil profiles (Figs. 2–4 and 6), as well as in other soil profiles excavated in the surroundings (Dimase et al., 1996; Scarciglia et al., 2008). In CL1 and CL2 the establishment of the Calabrian pine forest is marked by a significant increase in the SAL (Figs. 2 and 3), indicating higher fires frequency, in compliance with the easy flammability of coniferous woodlands (Robin et al., 2014). How to explain this strong environmental change? Climate proxy data indicates for this period the persistency of the general trend toward more arid conditions that seems to characterise southern Italy during the Mid-to Late Holocene (Frisia et al., 2006; Combourieu-Nebout et al., 2013; Magny et al., 2013; Peyron et al., 2013; Siani et al., 2013). Dry episodes at 3450-3200 BP are observed in the Aeolian Islands (north of Sicily; Caracuta et al., 2012) and low sedimentation rate at the Naples coastline also suggests drier conditions during the third and second millennium BP (Romano et al., 2013). In central Italy, on the other hand, wetter conditions seem to prevail (Fig. 10h; Magny et al., 2007; Di Bella et al., 2013). Closer to the study area, within the general trend toward drier conditions that characterise the late Holocene a period of deeper water at Lake Trifoglietti is documented between 3500 and 2500 BP (Joannin et al., 2012), in agreement with increased flooding events in the nearby Bradano valley at 3400-3100 BP (Piccarreta et al., 2011). Pollen records for this period display different vegetation patterns, showing a stable vegetation cover (e.g. Di Rita and Magri, 2009; Noti et al., 2009; Calò et al., 2012) or a progressive vegetation opening/change (e.g. Caroli and Caldara, 2007; Sadori et al., 2013). In the mountainous areas of southern Italy, the vegetation remains stable until 3000 BP at Monticchio Lake, when a decline of *Abies* is recorded and attributed by the authors to human exploitation (Allen et al., 2002). A moderate restoration of arboreal pollen after the Bronze Age opening is documented at Lake Trifoglietti (Fig. 8c; Joannin et al., 2012). At Cànolo Nuovo, the forest cover is stable, at least until between 3000 and 2000 BP, when *Abies* and *Fagus* show a slight decline (Schneider, 1985). The above-mentioned different vegetation patterns seems to rule out climate as the triggering factor of the vegetation changes in this period (as already evidenced by Tinner et al., 2009; Carrión et al., 2010; Magny et al., 2011). In fact, during the Bronze Age anthropogenic indicators start to be steadily and abundantly present in many pollen records along the Italian peninsula (e.g. Oldfield et al., 2003; Drescher-Schneider et al., 2007; Sadori et al., 2011; Mercuri et al., 2013). The human presence is well testified in the area of Cecita Lake from the Early to the Middle Bronze Age along the shore of the lake (Marino and Taliano Grasso, 2010). Interestingly, the Middle Bronze Age is characterized in southern Italy, and particularly in Calabria, by very important social and economic innovations connected with the stabilization of the settlement and a strong population increase, as clearly exemplified by the settlement dynamics in central-northern Calabria (Bettelli et al., 2004. See the settlement dynamics outlined in Fig. 8). The spread of metallurgy and of a specialized agriculture and animal husbandry are also fundamental aspects of this period (Peroni, 1996). Sites located in the hilly and mountainous areas develop in the region, as well documented by the settlements at Cecita Lake (Marino and Taliano Grasso, 2010): these sites are functional to animal husbandry, agriculture and to the control of the trade routes, and therefore of the raw materials such as minerals and timber, that connect the Sila plateau with both the Tyrrhenian and the Ionian Sea (Bettelli et al., 2004). During the Middle and Recent Bronze Age, moreover, the presence of Mycenaean seafarers is documented in Calabria along the coasts and in the inland areas (Bettelli et al., 2004). The population growth that characterise the Middle and Recent Bronze Age in Calabria and the establishment of a Mediterranean-wide trade network surely had an impact on the environment and strongly contributed in modifying the landscape in the surroundings of the settlements. In this period, for example, an important environmental change occurs also in the area of Punta Zambrone in southern Calabria in correspondence to the arrival of new population groups from northern Italy (D'Auria et al., 2016). At Cecita Lake, the human impact should have been particularly intense. In fact, despite the aridification trend observed during the Late Holocene, the persistency of a moderate humidity, with a reduced seasonal contrast, is still documented by the presence of clay coatings and by the prevalence of pedogenetic SROM vs. phyllosilicates (Pelle et al., 2013b), similarly to the archaeological site of Palmi in southwestern Calabria (Pelle et al., 2013a). The prominent role of the humans in the environmental change at Cecita Lake is further supported by the different trend attested at the nearby Lake Trifoglietti where both silver fir and deciduous oak recover after the decline during the Early Bronze Age (Fig. 8b; Joannin et al., 2012). These differences also highlight the high spatial resolution of soil charcoal analysis and show the importance of a multi-proxy approach for the reconstruction of past environmental changes.

The concentration of radiocarbon dates at 3300-2400 BP, when the Calabrian pine forest was already established at Cecita Lake (Fig. 2), roughly corresponds to Bond event 2 (Bond et al., 2001); in this period, cool conditions seem to prevail in the central Mediterranean (e.g. glacial advance: Fig. 10f: Giraudi et al., 2011. Cacho et al., 2001; Sangiorgi et al., 2003; Siani et al., 2013). Numerous human settlements are documented on the Sila plateau during the Iron Age, aimed at exploiting the resources deep into the territory (Marino, 2005). During the Greek Age, moreover, an important sanctuary is established on the shores of Cecita Lake, for which archaeological findings testify contacts with other Greek cities of Calabria and Sicily (Marino and Taliano Grasso, 2010). The human activities in the area are probably the main cause of the increased fire activity in this period.

5.2.6. The Late Holocene: evidence of land use and forest management

The last concentration of radiocarbon dates is visible only from ca. 600 BP to the present. Only one radiocarbon date refers to the Roman Age: a *Cornus* charcoal coming from a colluvial/alluvial layer in soil profile CL5 (Fig. 6). Sparse radiocarbon dates are found for the Middle Ages. The almost complete absence of radiocarbon dates during the Roman Age, considered as a period characterised by a strong human impact, can be surprising. However, if we look at the soil profiles, an explanation can be found. In fact, only CL1 and CL2 show the presence of a woody vegetation cover; the other soil profiles give strong evidence of an open landscape subjected to erosion and/or aggradation processes (this is the case of CL3, CL4 and CL5, which accordingly show very low SAL values) and/or to land use (as in CL5). The presence of Roman settlements around the lake is well documented by archaeological data with a large residential area of several thousands of square meters, a farm and a furnace for the production of pitch (Marino and Taliano Grasso, 2010). These data agree with the Roman literary sources, which testify the presence of *societates picariae* (i.e. companies for the exploitation of pitch) active on the Sila plateau and highlight the high quality of the local pitch and the significant income brought to the Roman state by its production (Cicero, *Brutus*, 22: Wilkins, 1911; Dionysus of Halicarnassus, *Antiquitates Romanae*, 20, 15: Jacoy,

Fig. 11. Human activity at Cecita Lake during Middle Ages and Modern times. a) small branches of Leguminosae from CL5. b) wavy bottom of the Ab horizon in CL5, possible indication of agricultural activities. c) notch cut in the trunk of a Calabrian pine tree to collect the resin for pitch production. a) Picture by D.M. b) and c) Pictures by O.N.

1885). During Roman time, the extraction of pitch from the wood of Calabrian pine entailed the burning of the wood inside furnaces with a process described by Pliny in its Natural History (16, 21: Bostock and Riley, 1855; see also Orengo et al., 2013). The large use of Calabrian pine for pitch production and other uses – Calabrian pine is almost the only taxon identified in the charcoal assemblage of the archaeological settlements at Cecita Lake (Pelle et al., 2013b) – probably implied a strict management of the wood resources in the area. The woodland management prevented the spread of forest fires, despite an oscillating climatic pattern with prevalent warm condition and the evidence of dry and cool spells (Dermody et al., 2012; McCormick et al., 2012; Taricco et al., 2009). In fact, limited evidence of environmental degradation during the Roman Age is documented also near Rome (Mensing et al., 2015) and Naples (Russo Ermolli et al., 2014).

During the Middle Ages, the exploitation of the territory for agriculture is testified by two radiocarbon dates from the Ab horizon of CL5 (Fig. 6). The charcoal assemblage of this horizon is composed exclusively by small branches of Leguminosae (Fig. 11), suggesting that fires affected the shrubby vegetation growing on abandoned fields (Figueiral and Bettencourt, 2004). Also nowadays on the Sila plateau abandonment fields are colonised by dense shrubs of *Cytisus scoparius* (Bernardo et al., 2010). This hypothesis seems to be confirmed by the wavy bottom of the Ab horizon, which could be a sign of past agricultural practices, such as ploughing (Fig. 11) and by the presence of *Secale* and *Triticum* type in the pollen assemblage from the same horizon (Fig. 7). In fact, the large presence of human settlements on the Sila plateau and its exploitation for agriculture and animal husbandry is attested during the Middle Ages by archaeological and historical data (Cherubini, 2005; Noyé, 2005).

The taxonomical identification of the last group of radiocarbon-dated charcoals shows the presence of *Pinus* group *sylvestris* and, in a lesser extent, *Fagus sylvatica*. The soil profiles show that the Calabrian pine forest is still present in this period at CL2 and probably at CL1 (Figs. 2 and 3). The charcoal assemblage of the upper level of CL5 (Ap horizon, Fig. 6) indicates the possible reforestation of the area after the deposition of a series of colluvial/alluvial layers, with the presence of a mixed vegetation dominated by Calabrian pine and beech. This group of radiocarbon dates roughly falls into the so-called “Little Ice Age” (Fischer et al., 1998; Chambers, 2015), a period characterised by general cool and wet conditions (Taricco et al., 2009; Chen et al., 2013; Giraudi, 2014; Benito et al., 2015; Sadori et al., 2016). A primary climatic cause for the increased fire activity seems, indeed, improbable. In fact, the human impact on the forests during the Middle Ages and Modern times is visible in many pollen records along Italy (e.g. Russo Ermolli and Di Pasquale, 2002; Di Rita and Magri, 2009; Calò et al., 2012; Sadori et al., 2016). In the nearby Lake Trifoglietti, regional reduction of the mixed-oak forest is observed between 800 and 33 BP (Joannin et al., 2012). This period is marked in Calabria by an increasing importance of agriculture and animal husbandry, involving also large areas on the Sila Plateau (Colapietra, 2005; Sirago, 2005), where slash-and-burn farming was probably practiced (Cherubini, 2005). Particularly severe phases of deforestation in Calabria are documented in the 17th and 18th centuries and the first half of the 20th century (Sorriso-Valvo, 1993), together with widespread illegal cuts of trees and arsons (Colapietra, 2005; Sirago, 2005).

As a final remark, the persistency of pure Calabrian pine forest until recent times (see CL1 and CL2), together with the very low presence of beech and the absence of deciduous oak in the upper horizons of our soils, testify the continuous human pressure in this area of the Sila plateau. In fact, as highlighted by Nicolaci et al. (2014) the absence of management and human pressure on the Calabrian pine forests of the Sila uplands, caused by the abandonment of the mountainous areas after the First World War, favours the evolution toward pure or mixed broadleaved forests dominated by oaks. On the contrary, the silvicultural systems used to manage pine forests until a recent past and the repeated fires, probably together with the management connected to the extraction of pitch from the living trees (Fig. 11; Gangemi, 2007), favoured the maintenance of the Calabrian pine woodlands, which survive nowadays only with scattered old-growth stands, as it is documented in the area of soil profiles CL1 and CL2 (Ciancio et al., 2010).

6. Conclusions

Soil charcoal analysis at Cecita Lake revealed itself as a useful tool for detecting local environmental changes with a high spatial resolution and, combined with a good number of radiocarbon dating, allowed us reconstructing the long-term vegetation changes and fire events of the area during the Holocene. To summarize, we can highlight the following:

- the episodes of increased fire activity recorded through the concentrations of radiocarbon dates fits well in the regional fire history;
- the comparison with different climate proxies suggests that the episodes of increased fire activity roughly corresponds to the main climatic events in the first part of the Holocene. From the Mid-to Late Holocene, the human action became the triggering factor of forest fires and of environmental changes, sometimes strengthening the effect of the climate variability, sometimes acting independently from it;
- a severe environmental degradation, followed by a significant vegetation shift took place in the area in the period between the Middle Bronze Age and the Final Bronze Age/Iron Age. The well documented human impact in the area was the primary cause of the environmental degradation and change, even if the climatic variability of the Holocene and the aridification trend of the Late Holocene probably facilitated the vegetation shift;
- the human pressure on the environment around Cecita Lake continued until recent times, favouring the maintenance of the Calabrian pine forest;
- the Calabrian pine forest, which today constitutes the typical forest vegetation of the Sila uplands, is a man-induced landscape, which established in this area ca. 3000 years ago.

In the light of these results, we clearly see the need of further multi-proxies investigations on the Sila plateau. Calabria, with its location in the centre of the Mediterranean basin, has in fact great importance in regards to the environmental history of this region of the Old World.

Acknowledgements

This research was funded through the DFG (German Research Foundation) financed Graduate School “Human Development in Landscapes” at Kiel University, by way of a grant to Daniela Moser. We are indebted to Dr Sebastien Joannin for providing artwork and information about the pollen record from Lake Trifoglietti and to Yasmin Dannath for the pollen analysis of soil profile CL5. We are grateful to Emilia Allevato, Mauro Buonincontri and Teresa Pelle for their help during the fieldwork. We would also like to thank two anonymous reviewers for their constructive comments.

References

Albert, B., Innes, J., 2015. Multi-profile fine-resolution palynological and microcharcoal analyses at Esklets, North York Moors, UK, with special reference to the Mesolithic-Neolithic transition. Veg. Hist. Archaeobot. 24, 357–375.

Allen, J.R.M., Watts, W.A., McGee, E., Huntley, B., 2002. Holocene environmental variability – the record from Lago Grande di Monticchio, Italy. Quat. Int. 88, 69–80.

Alley, R.B., Ágústsdóttir, A.M., 2005. The 8k event: cause and consequences of a major Holocene abrupt climate change. Quat. Sci. Rev. 24, 1123–1149.

Ammerman, A.J., 1979. A study of obsidian exchange networks in Calabria. World Archaeol. 11, 95–110.

Antonioli, F., Silenzi, S., Frisia, S., 2001. Tyrrhenian Holocene palaeoclimate trends from spelean serpulids. Quat. Sci. Rev. 20, 1661–1670.

Avolio, S., Ciancio, O., 1991. Prove di avviamento ad alto fusto di cedui di faggio in Sila. Ann. Ist. Sper. Selvic. 22 (1994), 191–226.

Avolio, S., Berbardini, V., Clerici, E., Addario, E., Turchetti, T., 2009–2010. Indagini selvicolturali e fitosanitarie in cedui di castagno della Sila (Calabria) situati a quote diverse e sottoposti a diradamento. Ann. CRA Ist. Sper. Selvic. 36, 15–24.

Bal, M.-C., Rendu, C., Ruas, M.-P., Campmajo, P., 2010. Paleosol charcoal: reconstructing vegetation history in relation to agro-pastoral activities since the Neolithic. A case study in the Eastern French Pyrenees. J. Archaeol. Sci. 37, 1785–1797.

Barbéro, M., Quézel, P., 1975. Les forêts de sapin sur le pourtour méditerranéen. In: Anales del Instituto Botànico A.J. Cavanilles, vol. 32, pp. 1245–1289.

Barbéro, M., Loisel, R., Quézel, P., Richardson, D.M., Romane, F., 1998. Pines of the Mediterranean Basin. In: Richardson, D.M. (Ed.), Ecology and Biogeography of Pinus. Cambridge University Press, Cambridge, pp. 153–170.

Bar-Matthwes, M., Ayalon, A., 2011. Mid-Holocene climate variations revealed by high-resolution speleothem records from Soreq Cave, Israel and their correlation with cultural changes. Holocene 21, 163–171.

Benito, G., Macklin, M.G., Zielhofer, C., Jones, A.F., Machado, M.J., 2015. Holocene flooding and climate change in the Mediterranean. Catena 130, 13–33.

Berger, J.-F., Guilaine, J., 2009. The 8200 cal BP abrupt environmental change and the Neolithic transition: a Mediterranean perspective. Quat. Int. 200, 31–49.

Bernardo, L., Cesca, G., Codogno, M., Fascetti, S., Puntillo, D., 1991. Studio fitosociologico e cartografia della vegetazione della Sila Greca (Calabria). Stud. Geobot. 11, 77–102.

Bernardo, L., Passalacqua, N., Spampinato, G., 2010. Le serie di vegetazione della Regione Calabria. In: Blasi, C. (Ed.), La vegetazione d'Italia. Palombi Editori, Roma, pp. 411–427.

Bettelli, M., Cardarelli, A., Di Gennaro, F., Levi, S.T., Marino, D., Pacciarelli, M., Peroni, R., Vagnetti, L., Vanzetti, A., 2004. L'età del Bronzo Media e Tarda in Calabria. Atti della XXXVII Riunione Scientifica. Preistoria e protostoria della Calabria. Istituto Italiano di Preistoria e Protostoria, Firenze, pp. 325–347.

Bond, G., Kromer, B., Beer, J., Muscheler, R., Evans, M.N., Showers, W., Hoffmann, S., Lotti-Bond, R., Hajdas, I., Bonani, G., 2001. Persistent solar influence on North Atlantic climate during the Holocene. Science 294, 2130–2136.

Bos, J.A.A., Urz, R., 2003. Late Glacial and early Holocene environment in the middle Lahn river valley (Hessen, central-west Germany) and the local impact of early Mesolithic people - pollen and macrofossil evidence. Veg. Hist. Archaeobot. 12, 19–36.

Bostock, J., Riley, H.T., 1855. The Natural History. Perseus Digital Library. http://perseus.tufts.edu/. Accessed 07 March 2016.

Bout-Roumazeilles, V., Combourieu-Nebout, N., Desprat, S., Siani, G., Turon, J.-L., Essellami, L., 2013. Tracking atmospheric and riverine terrigenous supplies variability during the last glacial and the Holocene in central Mediterranean. Clim. Past 9, 1065–1087.

Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51, 337–360.

Cacho, I., Grimalt, J.O., Canals, M., Sbaffi, L., Shackleton, N.J., Schönfeld, J., Zahn, R., 2001. Variability of the western Mediterranean Sea surface temperature during the last 25,000 years and its connection with the Northern hemisphere climatic changes. Paleoceanography 16, 40–52.

Calò, C., Henne, P.D., Curry, B., Magny, M., Vescovi, E., La Mantia, T., Pasta, S., Vannière, B., Tinner, W., 2012. Spatio-temporal patterns of Holocene environmental change in southern Sicily. Palaeogeogr. Palaeoclimatol. Palaeoecol. 323–325, 110–122.

Caracuta, V., Fiorentino, G., Martinelli, M.C., 2012. Plant remains and AMS: dating climate change in the Aeolian Islands (Northern Sicily) during the 2nd millennium BC. In: Boaretto, E., Reballo Franco, N.R. (Eds.), Proceedings of the 6th International Radiocarbon and Archaeology Symposium, Radiocarbon, vol. 54 (3–4), pp. 689–700.

Carancini, G.L., 2004. Note relative ai primi sviluppi della metallurgia nella penisola italiana alla luce della sequenza cronologica dell'Eneolitico di Grotta Pavolella (Cassano allo Jonio, CS). In: Atti della XXXVII Riunione Scientifica. Preistoria e protostoria della Calabria. Istituto Italiano di Preistoria e Protostoria, Firenze, pp. 251–258.

Carcaillet, C., 2001. Are Holocene wood-charcoal fragments stratified in alpine and subalpine soils? Evidence from the Alps based on AMS ^{14}C dates. Holocene 11, 231–242.

Carcaillet, C., Thinon, M., 1996. Pedoanthracological contribution to the study of the evolution of the upper treeline in the Maurienne Valley (North French Alps): methodology and preliminary data. Rev. Paleaobot. Palynol. 91, 399–416.

Caroli, I., Caldara, M., 2007. Vegetation history of Lago Battaglia (eastern Gargano coast, Apulia, Italy) during the middle-late Holocene. Veg. Hist. Archaeobot. 16, 317–327.

Carrión, J.S., 2002. Patterns and processes of Late Quaternary environmental change in a montane region of southwestern Europe. Quat. Sci. Rev. 21, 2047–2066.

Carrión, J.S., Fuentes, N., González-Sampériz, P., Sánchez Quirante, L., Finlayson, J.C., Fernández, S., Andrade, A., 2007. Holocene environmental change in a montane region of southern Europe with a long history of human settlement. Quat. Sci. Rev. 26, 1455–1475.

Carrión, J.S., Fernández, S., Jiménez-Moreno, G., Fauquette, S., Gil-Romera, G., Gonzáles-Sampériz, P., Finlayson, C., 2010. The historical origins of aridity and vegetation degradation in southern Spain. J. Arid Environ. 74, 731–736.

Chambers, F.M., 2015. The 'Little Ice Age': the first virtual issue of the Holocene. Holocene. http://dx.doi.org/10.1177/0959683615593688.

Chen, L., Zonneveld, K.A.F., Versteegh, G.J.M., 2013. Paleoclimate of the Southern Adriatic sea region during the 'Medieval Climate Anomaly' reflected by organic walled dinoflagellate cysts. Holocene 23, 645–655.

Cherubini, G., 2005. Le campagne. In: Placanica, A. (Ed.), Storia della Calabria medievale. I quadri generali. Gangemi, Roma, pp. 427–466.

Ciancio, O., 1971. Sul clima e sulla distribuzione altimetrica della vegetazione forestale in Calabria. Ann. dell'Istituto Sper. Selvic. 2, 323–372.

Ciancio, O., Iovino, F., Menguzzato, G., Nicolaci, A., Nocentini, S., 2006. Structure and growth of a small group selection forest of calabrian pine in Southern Italy: a hypothesis for continuous cover forestry based on traditional silviculture. For. Ecol. Manag. 224, 229–234.

Ciancio, O., Iovino, F., Menguzzato, G., Nicolaci, A., 2007. Interventi selvicolturali in cedui di faggio che hanno superato il turno consuetudinario e valutazione della biomassa legnosa ritraibile. L'Italia For. Montana 62 (5/6), 339–353.

Ciancio, O., Iovino, F., Menguzzato, G., Nicolaci, A., Veltri, A., 2010. Stand structure of a Calabrian pine old-growth forest: indications for forest management and landscape conservation. L'Italia For. Montana 65, 529–544.

Clark, J.S., 1988. Particle motion and the theory of charcoal analysis: source area, transport, deposition, and sampling. Quat. Res. 30, 67–80.

Clark, J.S., Patterson, W.A., 1997. Background and local charcoal in sediments: scales of fire evidence in the paleorecord. In: Clark, J.S., Cachier, H., Goldammer, J.G., Stocks, B. (Eds.), Sediment Records of Biomass Burning and Global Change, Proceedings of the NATO Advanced Study Institute "Biomass burning and global change", Praia de Alvor, Portugal, October 1994. Springer-Verlag, Berlin, Heidelberg, pp. 23–48.

Colapietra, R., 2005. La Calabria nel Cinquecento. In: Placanica, A. (Ed.), Storia della Calabria moderna e contemporanea, Il lungo periodo: dalla scoperta dell'America alla caduta del fascismo. Gangemi, Roma, pp. 143–207.

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

Combourieu-Nebout, N., Peyron, O., Bout-Roumazeilles, V., Goring, S., Dormoy, I., Joannin, S., Sadori, L., Siani, G., Magny, M., 2013. Holocene vegetation and climate changes in the central Mediterranean inferred from a high-resolution marine pollen record (Adriatic Sea). Clim. Past 9, 2023–2042.

Compostella, C., Trombino, L., Caccianiga, M., 2013. Late Holocene soil evolution and treeline fluctuations in the Northern Apennines. Quat. Int. 289, 46–59.

Costantini, E.A.C., 1993. Surface morphology and thinning grade effect on soils of a Calabrian Pine plantation in the Sila Mountain (Calabria, Italy). Geogr. Fis. Din. Quat. 16, 29–35.

D'Auria, A., Buonincontri, M., Allevato, E., Jung, R., Piacciarelli, M., Saracino, A., Di Pasquale, G., 2016. Evidence of a short-lived episode of olive (Olea europaea L.) cultivation in the Early Bronze Age as revealed by southern Italian charcoal data. Holocene. http://dx.doi.org/10.1177/0959683616670218.

Dermody, B.J., de Boer, H.J., Bierkens, M.F.P., Weber, S.L., Wassen, M.J., Dekker, S.C., 2012. A seesaw in Mediterranean precipitation during the Roman Period linked to millennial-scale changes in the North Atlantic. Clim. Past 8, 637–651.

Desprat, S., Combourieu-Nebout, N., Essellami, L., Sicre, M.A., Dormoy, I., Peyron, O., Siani, G., Bout Roumazeilles, V., Turon, J.L., 2013. Deglacial and Holocene vegetation and climate changes in the southern Central Mediterranean from a direct land-sea correlation. Clim. Past 9, 767–787.

Dimase, A.C., Iovino, F., Bonazzi, A., 1996. Effetti dell'impatto antropico sull'erosione dei suoli dell'altopiano della Sila (Calabria). Ann. dell'Accad. Ital. Sci. For. 45, 307–329.

Di Bella, L., Bellotti, P., Milli, S., 2013. The role of foraminifera as indicators of the Late Pleistocene-Holocene palaeoclimatic fluctuations on the deltaic environment: the example of Tiber delta succession (Tyrrhenian margin, Italy). Quat. Int. 303, 191–209.

Di Donato, V., Esposito, P., Russo Ermolli, E., Cheddadi, R., Scarano, A., 2008. Coupled atmospheric and marine palaeoclimatic reconstruction for the last 35 kyr in the Sele Plain-Gulf of Salerno area (southern Italy). Quat. Int. 190, 146–157.

Di Pasquale, G., Mazzoleni, S., 2002. Late Holocene vegetation dynamics in the Cilento region (southern Italy): preliminary data. In: Thiebault, S. (Ed.), Charcoal Analysis: methodological Approaches, Palaeoecological Results and Wood Issues, BAR International Series,, pp. 127–132.

Di Pasquale, G., Allevato, E., Cocchiararo, A., Moser, D., Pacciarelli, M., Saracino, A., 2014. Late Holocene persistence of Abies alba in low-mid altitude deciduous forests of central and southern Italy: new perspectives from charcoal data. J. Veg. Sci. 25, 1299–1310.

Di Rita, F., 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. Holocene 19, 295–306.

Di Rita, F., Anzidei, A.P., Magri, D., 2013. A Lateglacial and early Holocene pollen record from Valle di Castiglione (Rome): vegetation dynamics and climate implications. Quat. Int. 288, 73–80.

Drescher-Schneider, R., de Beaulieu, J.L., Magny, M., Walter-Simmonet, A.V., Bossuet, G., Millet, L., Brugiapaglia, E., Drescher, A., 2007. Vegetation history, climate and human impact over the last 15000 years at Lago dell'Accesa (Tuscany, Central Italy). Veg. Hist. Archaeobot. 16, 279–299.

Drysdale, R., Zanchetta, G., Hellstrom, J., Maas, R., Fallick, A., Pickett, M., Cartwright, I., Piccini, L., 2006. Late Holocene drought responsible for the collapse of Old World civilizations is recorded in an Italian cave flowstone. Geology 34, 101–104.

Egli, M., Mastrolonardo, G., Seiler, R., Raimondi, S., Favilli, F., Crimi, V., Krebs, R., Cherubini, P., Certini, G., 2012. Charcoal and stable soil organic matter as indicators of fire frequency, climate and past vegetation in volcanic soils of Mt. Etna, Sicily. Catena 88, 14–26.

Emeis, K.-C., Struck, U., Schulz, H.-M., Rosenberg, R., Bernasconi, S., Erlenkeuser, H., Sakamoto, T., Martinez-Ruiz, F., 2000. Temperature and salinity variations of Mediterranean Sea surface waters over the last 16,000 years from records of planktonic stable oxygen isotopes and alkenone unsaturation ratios. Palaeogeogr. Palaeoclimatol. Palaeoecol. 158, 259–280.

Faegri, K., Iversen, J., 1989. Textbook of Pollen Analysis, fourth ed. John Wiley & Sons, Chichester.

Favilli, F., Cherubini, P., Collenberg, M., Egli, M., Sartori, G., Schoch, W., Haeberli, W., 2010. Charcoal fragments of Alpine soils as an indicator of landscape evolution during the Holocene in Val di Sole (Trentino, Italy). Holocene 20, 67–79.

Ferrarini, E., 1978. Analisi polliniche di fanghi di acquitrini della Sila Grande. Inf. Bot. Ital. 10, 40–43.

Figueiral, I., Bettencourt, A.M.S., 2004. Middle/Late Bronze Age plant communities and their exploitation in the Cávado Basin (NW Portugal) as shown by charcoal analysis: the significance and co-occurrenec of Quercus (deciduous) – Fabaceae. Veg. Hist. Archaeobot. 13, 219–232.

Fischer, H., Werner, M., Wagenbach, D., Schwager, M., Thorsteinnson, T., Wilhelms, F., Kipfstuhl, J., Sommers, S., 1998. Little Ice Age clearly recorded in northern Greenland ice cores. Geophys. Res. Lett. 25, 1749–1752.

Forbes, M.S., Raison, R.J., Skjemstad, J.O., 2006. Formation, transformation and transport of black carbon (charcoal) in terrestrial and aquatic ecosystems. Sci. Total Environ. 370, 190–206.

Fréjaville, T., Carcaillet, C., Curt, T., 2013. Calibration of charcoal production from trees biomass for soil chrcoal analyses in subalpine ecosystems. Quat. Int. 289, 16–23.

Frisia, S., Borsato, A., Mangini, A., Spötl, C., Madonia, G., Sauro, U., 2006. Holocene climate variability in Sicily from a discontinuous stalagmite record and the Mesolithic to Neolithic transition. Quat. Res. 66, 388–400.

Gangemi, M., 2007. Pitch production during the 18th century in the Calabrian Sila (Italy). For. Ecol. Manag. 249, 39–44.

Gavin, D.G., Brubaker, L.B., Lertzman, K.P., 2003. Holocene fire history of a coastal temperate rain forest based on soil charcoal radiocarbon dates. Ecology 84, 186–201.

Giardini, M., 2007. Late Quaternary vegetation history at Stracciacappa (Rome, central Italy). Veg. Hist. Archaeobot. 16, 301–316.

Giraudi, C., 2014. Coarse sediments in Northern Apennine peat bogs and lakes: new data for the record of Holocene alluvial phases in peninsular Italy. Holocene 24, 932–943.

Giraudi, C., Magny, M., Zanchetta, G., Drysdale, R.N., 2011. The Holocene climatic evolution of Mediterranean Italy; a review of the continental geological data. Holocene 21, 105–115.

Greguss, P., 1955. Identification of Living Gymnosperms on the Basis of Xylotomy. Akadémiai Kiadò, Budapest.

Greguss, P., 1959. Holzanatomie der Europäischen Laubhölzer und Sträucher. Akadémiai Kiadò, Budapest.

Guzzo, P.G., 1989. I Brettii. Storia e archeologia della Calabria preromana. In: Biblioteca di archeologia, vol. 12. Longanesi &C., Milano.

Innes, J.B., Blackford, J.J., Rowley-Conwy, P., 2013. Late Mesolithic and early Neolithic forest disturbance: a high resolution palaeoecological test of human impact hypotheses. Quat. Sci. Rev. 77, 80–100.

Jacoby, K., 1885. Dionysii Halicarnasei Antiquitatum Romanarum quae supersunt, vols. I-IV. Perseus Digital Library. http://perseus.tufts.edu/. Accessed 07 March 2016.

Jahns, S., 1993. On the Holocene vegetation history of the Argive Plain (Peloponnese, southern Greece). Veg. Hist. Archaeobot. 2, 187–203.

Jahns, S., van den Bogaard, C., 1998. New palynological and tephrostratigraphical investigations of two salt lagoons on the island of Mljet, south Dalmatia, Croatia. Veg. Hist. Archaeobot. 7, 219–234.

Joannin, S., Brugiapaglia, E., de Beaulieu, J.-L., Bernardo, L., Magny, M., Peyron, O., Goring, S., Vannière, B., 2012. Pollen-based reconstruction of Holocene vegetation and climate in southern Italy: the case of Lago Trifoglietti. Clim. Past 8, 1973–1996.

Joannin, S., Magny, M., Peyron, O., Vannière, B., Galop, D., 2014. Climate and land-use change during the late Holocene at Lake Ledro (southern Alps, Italy). Holocene 24, 591–602.

Kallel, N., Paterne, M., Labeyrie, L., Duplessy, J.-C., Arnold, M., 1997. Temperature and salinity records of the Tyrrhenian Sea during the last 18,000 years. Palaeogeogr. Palaeoclimatol. Palaeoecol. 135, 97–108.

Kaltenrieder, P., Procacci, G., Vannière, B., Tinner, W., 2010. Vegetation and fire history of the Euganean Hills (Colli Euganei) as recorded by Lateglacial and Holocene sedimentary series from Lago della Costa (northeastern Italy). Holocene 20, 679–695.

Lombardo, M., 1989. I Brettii. In: Ampolo, C., Briquel, D., Càssola Guida, P., D'Agostino, B., De Simone, C., La Regina, A., La Rosa, V., Lejeune, M., Lombardo, M., Negroni Catacchio, N., Parise, N.F., Peroni, R., Prosdocimi, A.L., Pugliese Carratelli, G. (Eds.), Italia omnium terrarum parens. La civiltà degli Enotri, Choni, Ausoni, Sanniti, Lucani, Brettii, Sicani, Siculi, Elimi. Libri Scheiwiller, Milano, pp. 247–297.

Lowe, J.J., Davite, C., Moreno, D., Maggi, R., 1994. Holocene pollen stratigraphy and human interference in the woodlands of the northern Apennines, Italy. Holocene 4, 153–164.

Magny, M., de Beaulieu, J.-L., Drescher-Schneider, R., Vannière, B., Walter-Simonnet, A.-V., Miras, Y., Millet, L., Bossuet, G., Peyron, O., Brugiapaglia, E., Leroux, A., 2007. Holocene climate changes in the central Mediterranean as recorded by lake-level fluctuations at Lake Accesa (Tuscany, Italy). Quat. Sci. Rev. 26, 1736–1758.

Magny, M., Vannière, B., Zanchetta, G., Fouache, E., Touchais, G., Petrika, L., Coussot, C., Walter-Simonnet, A.-V., Arnaud, F., 2009. Possible complexity of the climatic event around 4300-3800 cal. BP in the central and western Mediterranean. Holocene 19, 823–833.

Magny, M., Vannière, B., Calò, C., Millet, L., Leroux, A., Peyron, O., Zanchetta, G., La Mantia, T., Tinner, W., 2011. Holocene hydrological changes in south-western Mediterranean as recorded by lake-level fluctuations at Lago Preola, a coastal lake in southern Sicily, Italy. Quat. Sci. Rev. 30, 2459–2475.

Magny, M., Peyron, O., Sadori, L., Ortu, E., Zanchetta, G., Vannière, B., Tinner, W., 2012. Contrasting patterns of precipitation seasonality during the Holocene in the south- and north-central Mediterranean. J. Quat. Sci. 27, 290–296.

Magny, M., Combourieu-Nebout, N., de Beaulieu, J.L., Bout-Roumazeilles, V., Colombaroli, D., Desprat, S., Francke, A., Joannin, S., Ortu, E., Peyron, O., Revel, M., Sadori, L., Siani, G., Sicre, M.A., Samartin, S., Simonneau, A., Tinner, W., Vannière, B., Wagner, B., Zanchetta, G., Anselmetti, F., Brugiapaglia, E., Chapron, E., Debret, M., Desmet, M., Didier, J., Esselami, L., Galop, D., Gilli, A., Haas, J.N., Kallel, N., Millet, L., Stock, A., Turon, J.L., Wirth, S., 2013. North-south palaeohydrological contrasts in the central Mediterranean during the Holocene: tentative synthesis and working hypotheses. Clim. Past 9, 2043–2071.

Marino, D., 2005. Kroton prima dei Greci. La prima età del Ferro nella Calabria centrale ionica. Rivista di Scienze Preistoriche LV, pp. 439–464.

Marino, D., Pacciarelli, M., 1996. Calabria. In: Cocchi Genik, D. (Ed.), L'antica età del Bronzo. Atti del Congresso di Viareggio. Franco Cantini Editore, Firenze, pp. 147–162.

Marino, D., Taliano Grasso, A., 2010. Ricerche topografiche e scavi archeologici nella Sila Grande. In: Rivista di Studi di Topografia Antica. Atlante tematico di topografia antica, ATTA, vol. 20, pp. 51–78.

Martini, F., 2004. Il Paleolitico superiore e il Mesolitico della Calabria. In: Atti della XXXVII Riunione Scientifica. Preistoria e protostoria della Calabria. Istituto Italiano di Preistoria e Protostoria, Firenze, pp. 35–58.

McCormick, M., Büntgen, U., Cane, M.A., Cook, E.R., Harper, K., Huybers, P., Litt, T., Manning, S.W., Mayewski, P.A., More, A.F.M., Nicolussi, K., Tegel, W., 2012. Climate change during and after the Roman Empire: reconstructing the past from scientific and historical evidence. J. Interdiscip. Hist. XLIII (2), 169–220.

Menguzzato, G., 2013. La gestione dei sistemi forestali nel Parco Nazionale della Sila. Sinergie, Rapp. Ric. 37, 111–119.

Mensing, S.A., Tunno, I., Sagnotti, L., Florindo, F., Noble, P., Archer, C., Zimmerman, S., Pavón-Carrasco, F.J., Cifani, G., Passigli, S., Piovesan, G., 2015. 2700 years of Mediterranean environmental change in central Italy: a synthesis of sedimentary and cultural records to interpret past impacts of climate on society. Quat. Sci. Rev. 116, 72–94.

Mercuri, A.M., Bandini Mazzanti, M., Torri, P., Vigliotti, L., Bosi, G., Florenzano, A., Olmi, L., Massamba N'siala, I., 2012. A marine/terrestrial integration for mid-late Holocene vegetation history and the development of the cultural landscape in the Po valley as a result of human impact and climate change. Veg. Hist. Archaeobot. 21, 353–372.

Mercuri, A.M., Bandini Mazzanti, M., Florenzano, A., Montecchi, M.C., Rattighieri, E., 2013. Olea, Juglans and Castanea: the OJC group as pollen evidence of the development of human-induced environments in the Italian peninsula. Quat. Int. 303, 24–42.

Moore, J., 2000. Forest fire and human interaction in the early Holocene woodlands of Britain. Palaeogeogr. Palaeoclimatol. Palaeoecol. 164, 125–137.

Moore, P.D., Webb, J.A., Collison, M.E., 1991. Pollen Analysis, second ed. Wiley Blackwell, Oxford.

Nelle, O., 2003. Woodland history of the last 500 years revealed by anthracological studies of charcoal kiln sites in the Bavarian Forest, Germany. Phytocoenologia 33, 667–682.

Nelle, O., Robin, V., Talon, B., 2013. Pedoanthracology: Analysing soil charcoal to study Holocene palaeoenvironments. Quat. Int. 289, 1–4.

Nicolaci, A., Travaglini, D., Menguzzato, G., Nocentini, S., Veltri, A., Iovino, F., 2014. Ecological and anthropogenic drivers of Calabrian pine (Pinus nigra J.F. Arn. ssp. laricio (Poiret) Maire) distribution in the Sila mountain range. iForest 8, 497–508.

Noti, R., van Leeuwen, J.F.N., Colombaroli, D., Vescovi, E., Pasta, S., La Mantia, T., Tinner, W., 2009. Mid- and late-Holocene vegetation and fire history at Biviere di Gela, a coastal lake in southern Sicily, Italy. Veg. Hist. Archaeobot. 18, 371–387.

Ohlson, M., Tryterud, E., 2000. Interpretation of the charcoal record in forest soils: forest fires and their production and deposition of macroscopic charcoal. Holocene 10, 519–525.

Oldfield, F., Asioli, A., Accorsi, C.A., Mercuri, A.M., Juggings, S., Langone, L., Rolph, T., Trincardi, F., Wolff, G., Gibbs, Z., Vigliotti, L., Frignani, M., van der Post, K., Branch, N., 2003. A high resolution late Holocene palaeo environmental record from the central Adriatic Sea. Quat. Sci. Rev. 22, 319–342.

Orengo, H.A., Palet Martínez, J.M., Ejarque, A., Miras, Y., Riera-Mora, S., 2013. Pitch production during the Roman period: an intensive mountain industry for a globalised economy? Antiquity 87, 802–814.

Pacciarelli M., 2011. L'Eneolitico della Calabria tirrenica: nuovi dati sull'articolazione cronoculturale. Origini XXXIII, Nuova Serie V, 249-302.

Pacciarelli, M., Talamo, T., 2011. Sull'articolazione dell'età del Rame nell'Italia meridionale tirrenica. In: Atti della XLIII Riunione Scientifica, L'età del Rame in Italia. Istituto Italiano di Preistoria e Protostoria, Firenze, pp. 87–94.

Palma di Cesnola, A., 2004. Il Paleolitico inferiore e medio della Calabria. In: Atti della XXXVII Riunione Scientifica, Preistoria e protostoria della Calabria. Scalea, Papasidero, Praia a Mare, Tortora. Istituto Italiano di Preistoria e Protostoria, Firenze, pp. 19–34.

Pelle, T., Scarciglia, F., Allevato, E., Di Pasquale, G., La Russa, M.F., Marino, D., Natali, E., Robustelli, G., Tiné, V., 2013a. Reconstruction of Holocene environmental changes in two archaeological sites of Calabria (Southern Italy) using an integrated pedological and anthracological approach. Quat. Int. 288, 206–214.

Pelle, T., Scarciglia, F., Di Pasquale, G., Allevato, E., Marino, D., Robustelli, G., La Russa, M.F., Pulice, I., 2013b. Multidisciplinary study of Holocene archaeological soils in an upland Mediterranean site: natural versus anthropogenic environmental changes at Cecita Lake, Calabria, Italy. Quat. Int. 303, 163–179.

Peroni, R., 1996. L'Italia alle soglie della storia. Laterza, Roma-Bari.

Peyron, O., Magny, M., Goring, S., Joannin, S., de Beaulieu, J.-L., Brugiapaglia, E., Sadori, L., Garfi, G., Kouli, K., Ioakim, C., Combourieu-Nebout, N., 2013. Contrasting patterns of climatic changes during the Holocene across the Italian Peninsula reconstructed from pollen data. Clim. Past 9, 1233–1252.

Piccarreta, M., Caldara, M., Capolongo, D., Boenzi, F., 2011. Holocene geomorphic activity related to climatic change and human impact in Basilicata, Southern Italy. Geomorphology 128, 137–147.

Pignatti, S., 1982. Flora d'Italia. Edagricole, Bologna.

Pyne, S.J., Goldammer, J.G., 1997. The culture of fire: an introduction to anthropogenic fire history. In: Clark, J.S., Cachier, H., Goldammer, J.G., Stocks, B. (Eds.), Sediment Records of Biomass Burning and Global Change, Proceedings of the NATO Advanced Study Institute “Biomass burning and global change”, Praia de Alvor, Portugal, October 1994. Springer-Verlag, Berlin, Heidelberg, pp. 71–114.

Quézel, P., Médail, F., 2003. Ecologie et biogéographie des forêts du Bassin Méditerranéen. Elsevier, Paris.

Ramsey, M.N., Jones, M., Richter, T., Rosen, A.M., 2015. Modifying the marsh: evaluating Early Epipaleolithic hunter-gatherer impacts in the Azraq wetland, Jordan. Holocene 25, 1553–1564.

Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P., Bronk Ramsey, C., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Haflidason, H., Hajdas, I., Hatté, C., Heaton, T.J., Hoffmann, D.L., Hogg, A.G., Hughen, K.A., Kaiser, K.F., Kromer, B., Manning, S.W., Niu, M., Reimer, R.W., Richards, D., Scott, E.M., Southon, J., Staff, R.A., Turney, C.S.M., van der Plicht, J., 2013. IntCal13 and Marine13 radiocarbon age calibration curves 0-50,000 years cal BP. Radiocarbon 55, 1869–1887.

Roberts, N., Reed, J.M., Leng, M.J., Kuzucuoğlu, C., Fontugne, M., Bertaux, J., Woldring, H., Bottema, S., Black, S., Hunt, E., Karabiyikoğlu, M., 2001. The tempo of Holocene climatic change in the eastern Mediterranean region: new high-resolution crater-lake sediment data from central Turkey. Holocene 11, 721–736.

Roberts, N., Brayshaw, D., Kuzucuoglu, C., Perez, R., Sadori, L., 2011. The mid-Holocene climatic transition in the Mediterranean: causes and consequences. Holocene 21, 3–13.

Robin, V., Rickert, B.-H., Nadeau, M.-J., Nelle, O., 2012. Assessing Holocene vegetation and fire history by a multiproxy approach: the case of Stodthagen Forest (northern Germany). Holocene 22, 337–346.

Robin, V., Knapp, H., Bork, H.-R., Nelle, O., 2013. Complementary use of pedoanthracology and peat macro-charcoal analysis for fire history assessment: illustration from Central Germany. Quat. Int. 289, 78–87.

Robin, V., Bork, H.-R., Nadeau, M.-J., Nelle, O., 2014. Fire and forest history of central European low mountain forest sites based on soil charcoal analysis: the case of the eastern Harz. Holocene 24, 35–47.

Rohling, E.J., 1994. Review and new aspects concerning the formation of eastern Mediterranean sapropels. Mar. Geol. 122, 1–28.

Roma, G., 2010. Nefandissimi Langobardi: mutamenti politici e frontiera altomedievale tra Ducato di Benevento e Ducato di Calabria. In: Roma, G. (Ed.), I Longobardi del Sud. Giorgio Bretschneider Editore, Roma, pp. 405–463.

Romano, P., Di Vito, M.A., Giampaola, D., Cinque, A., Bartoli, C., Boenzi, G., Detta, F., Di Marco, M., Giglio, M., Iodice, S., Liuzza, V., Ruello, M.R., Schiano di Cola, C., 2013. Intersection of exogenous, endogenous and anthropogenic factors in the Holocene landscape: a study of the Naples coastline during the last 6000 years. Quat. Int. 303, 107–119.

Rossignol-Strick, M., 1999. The Holocene climatic optimum and the pollen record of sapropel 1 in the eastern Mediterranean, 9000-6000 BP. Quat. Sci. Rev. 18, 515–530.

Russo Ermolli, E., Di Pasquale, G., 2002. Vegetation dynamics of south-western Italy in the last 28 kyr inferred from pollen analysis of a Tyrrhenian Sea core. Veg. Hist. Archaeobot. 11, 211–219.

Russo Ermolli, E., Romano, P., Ruello, M.R., Barone Lumaga, M.R., 2014. The natural and cultural landscape of Naples (southern Italy) during the Graeco-Roman and Late Antique periods. J. Archaeol. Sci. 42, 399–411.

Sadori, L., Giardini, M., 2007. Charcoal analysis, a method to study vegetation and climate of the Holocene: the case of Lago di Pergusa (Sicily, Italy). Geobios 40, 173–180.

Sadori, L., Narcisi, B., 2001. The postglacial record of environmental history from Lago di Pergusa (Sicily). Holocene 11, 655–671.

Sadori, L., Giraudi, C., Petitti, P., Ramrath, A., 2004. Human impact at Lago di Mezzano (central Italy) during the Bronze Age: a multidisciplinary approach. Quat. Int. 113, 5–17.

Sadori, L., Zanchetta, G., Giardini, M., 2008. Last Glacial to Holocene palaeoenvironmental evolution at Lago di Pergusa (Sicily, Southern Italy) as inferred by pollen, microcharcoal, and stable isotopes. Quat. Int. 181, 4–14.

Sadori, L., Jahns, S., Peyron, O., 2011. Mid-Holocene vegetation history of the central Mediterranean. Holocene 21, 117–129.

Sadori, L., Ortu, E., Peyron, O., Zanchetta, G., Vennière, B., Desmet, M., Magny, M., 2013. The last 7 millennia of vegetation and climate changes at Lago di Pergusa (central Sicily, Italy). Clim. Past 9, 1969–1984.

Sadori, L., Giraudi, C., Masi, A., Magny, M., Ortu, E., Zanchetta, G., Izdebski, A., 2016. Climate, environment and society in southern Italy during the last 2000 years. A review of the environmental, historical and archaeological evidence. Quat. Sci. Rev. 136, 173–188.

Salerno, A., Vanzetti, A., 2004. L'Eneolitico e il Bronzo Antico in Calabria. In: Atti della XXXVII Riunione Scientifica. Preistoria e protostoria della Calabria. Istituto Italiano di Preistoria e Protostoria, Firenze, pp. 207–234.

Sangiorgi, F., Capotondi, L., Combourieu-Nebout, N., Vigliotti, L., Brinkhuis, H., Giunta, S., Lotter, A.F., Morigi, C., Negri, A., Reichart, G.-J., 2003. Holocene seasonal sea-surface temperature variations in the southern Adriatic Sea inferred from a multiproxy approach. J. Quat. Sci. 18, 723–732.

Scarciglia, F., Terribile, F., Colombo, C., Cinque, A., 2003. Late Quaternary climatic changes in Northern Cilento (Southern Italy): an integrated geomorphological and paleopedological study. Quat. Int. 106–107, 141–158.

Scarciglia, F., Le Pera, E., Vecchio, G., Critelli, S., 2005. The interplay of geomorphic processes and soil development in an upland environment, Calabria, South Italy. Geomorphology 69, 169–190.

Scarciglia, F., Pulice, I., Robustelli, G., Vecchio, G., 2006. Soil chronosequences on Quaternary marine terraces along the northwestern coast of Calabria (Southern Italy). Quat. Int. 156–157, 133–155.

Scarciglia, F., De Rosa, R., Vecchio, G., Apollaro, C., Robustelli, G., Terrasi, F., 2008. Volcanic soil formation in Calabria (southern Italy): the Cecita Lake geosol in the late Quaternary geomorphological evolution of the Sila uplands. J. Volcanol. Geotherm. Res. 177, 101–117.

Scarciglia, F., Robustelli, G., Tiné, V., La Russa, M.F., Abate, M., Pezzino, A., 2009. The role of human impacts and Holocene climate change in the Santuario della Madonna Cave (Calabria). Méditerranée 112, 137–143.

Schneider, R., 1985. Analyse palynologique dans l'Aspromonte en Calabre (Italie meridionale). Cahiers Ligures de Préhistoire et de Protohistoire N.S. 2, 279–288.

Schweingruber, F.H., 1990. Anatomy of European Wood. Paul Haupt Verlag, Bern, Stuttgart.

Schwertmann, U., Taylor, R.M., 1989. Iron oxides. In: Dixon, J.B., Weed, S.B. (Eds.), Minerals in Soil Environments, second ed. Soil Science Society of America, Madison, WI, pp. 379–438.

Scott, A.C., Cripps, J.A., Collinson, M.E., Nichols, G.J., 2000. The taphonomy of charcoal following a recent heathland fire and some implications for the interpretation of fossil charcoal deposits. Palaeogeogr. Palaeoclimatol. Palaeoecol. 164, 1–31.

Siani, G., Magny, M., Paterne, M., Debret, M., Fontugne, M., 2013. Paleohydrology reconstruction and Holocene climate variability in the South Adriatic Sea. Clim. Past 9, 499–515.

Sirago, M., 2005. La Calabria nel Seicento. In: Placanica, A. (Ed.), Storia della Calabria moderna e contemporanea, Il lungo periodo: dalla scoperta dell'America alla caduta del fascismo. Gangemi, Roma, pp. 209–299.

Sorriso-Valvo, M., 1993. The geomorphology of Calabria. A sketch. Geogr. Fis. Din. Quat. 16, 75–80.

Talon, B., 2010. Reconstruction of Holocene high-altitude vegetation cover in the French southern Alps: evidence from soil charcoal. Holocene 20, 35–44.

Taricco, C., Ghil, M., Alessio, S., Vivaldo, G., 2009. Two millennia of climate variability in the Central Mediterranean. Clim. Past 5, 171–181.

Théry-Parisot, I., Chabal, L., Chrzavzez, J., 2010. Anthracology and taphonomy, from wood gathering to charcoal analysis. A review of the taphonomic processes modyfing charcoal assemblages, in archaeological contexts. Palaeogeogr. Palaeoclimatol. Palaeoecol. 291, 142–153.

Thinon, M., 1978. La pédoanthracologie: une nouvelle méthode d'analyse phytochronologique depuis le Néolithique. Comptes Rendus l'Acad. Sci. Ser. Sci. Nat. 287, 1203–1206.

Thinon, M., 1992. L'analyse pédoanthracologique – Aspect méthodologique et applications. Thése d'état, Université Aix-Marseille III, Marseille.

Tiné, S., 1987. Il Neolitico. In: Cingari, G., Settis, S. (Eds.), Storia della Calabria. La Calabria antica. Gangemi, Roma, pp. 39–64.

Tinner, W., van Leeuwen, J.F.N., Colombaroli, D., Vescovi, E., van der Knaap, W.O., Henne, P.D., Pasta, S., D'Angelo, S., La Mantia, T., 2009. Holocene environmental and climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy. Quat. Sci. Rev. 28, 1498–1510.

Tinner, W., Colombaroli, D., Heiri, O., Henne, P.D., Steinacher, M., Untenecker, J., Vescovi, E., Allen, J.R.M., Carraro, G., Valsecchi, V., 2013. The past ecology of Abies alba provides new perspectives on future responses of silver fir forests to global warming. Ecol. Monogr. 83, 419–439.

Torrent, J., Schwertmann, U., Schulze, D.J., 1980. Iron oxide mineralogy of some soils of two river terrace sequences in Spain. Geoderma 23, 191–208.

Valsecchi, V., Tinner, W., Finsinger, W., Ammann, B., 2006. Human impact during the Bronze Age on the vegetation at Lago Lucone (northern Italy). Veg. Hist. Archaeobot. 15, 99–113.

Vannière, B., Colombaroli, D., Chapron, E., Leroux, A., Tinner, W., Magny, M., 2008. Climate versus human-driven fire regimes in Mediterranean landscapes: the Holocene record of Lago dell'Accesa (Tuscany, Italy). Quat. Sci. Rev. 27, 1181–1196.

Vannière, B., Power, M.J., Roberts, N., Tinner, W., Carrión, J., Magny, M., Bartlein, P., Colombaroli, D., Daniau, A.L., Finsinger, W., Gil-Romera, G., Kaltenrieder, P., Pini, R., Sadori, L., Turner, R., Valsecchi, V., Vescovi, E., 2011. Circum-Mediterranean fire activity and climate changes during the mid-Holocene environmental transition (8500-2500 cal. BP). Holocene 21, 53–73.

Vescovi, E., Ammann, B., Ravazzi, C., Tinner, W., 2010. A new Late-glacial and Holocene record of vegetation and fire history from Lago del Greppo, northern Apennines, Italy. Veg. Hist. Archaeobot. 19, 219–233.

Warren, G., Davis, S., McClatchie, M., Sands, R., 2014. The potential role of humans in structuring the wooded landscapes of Mesolithic Ireland: a review of data and discussion of approaches. Veg. Hist. Archaeobot. 23, 629–646.

Wilkins, A.S., 1911. M. Tulli Ciceronis Rhetorica, Tomus II. Perseus Digital Library. http://www.perseus.tufts.edu/. Accessed 07 March 2016.

Yasuda, Y., Kitagawa, H., Nakagawa, T., 2000. The earliest record of major anthropogenic deforestation in the Ghab valley, north-west Syria: a palynological study. Quat. Int. 73/74, 127–136.

Zanchetta, G., Drysdale, R.N., Hellstrom, J.C., Fallick, A.E., Isola, I., Gagan, M.K., Pareschi, M.T., 2007. Enhanced rainfall in the Western Mediterranean during deposition of sapropel S1: stalagmite evidence from Corchia cave (Central Italy). Quat. Sci. Rev. 26, 279–286.

Zanchetta, G., Bini, M., Cremaschi, M., Magny, M., Sadori, L., 2013. The transition from natural to anthropogenic-dominated environmental change in Italy and the surrounding regions since the Neolithic: an introduction. Quat. Int. 303, 1–9.

Zapata, L., López-Sáez, J.A., Ruiz-Alonso, M., Linstädter, J., Pérez-Jordà, G., Morales, J., Kehl, M., Peña-Chocarro, L., 2013. Holocene environmental change and human impact in NE Morocco: Palaeobotanical evidence from Ifri Oudadane. Holocene 23, 1286–1296.