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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

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Abstract Integration of pollen data from both marine and terrestrial cores contributes to the understanding of the timing of the climatic and human forces that shaped the cultural landscapes in the Italian peninsula. This paper focuses on the relation between natural and human landscapes, and the development of the cultural landscape from the Bronze Age to the medieval period and modern times. Two records were studied within independent projects, first the marine core RF93-30, from the central Adriatic, with a sediment source area including the Po valley and which spans the last 7,000 years, and secondly, material from the site of Terramara di Montale, a Bronze Age settlement on the Po plain, which was occupied from approximately 3550–3200 cal. B.P. The original chronology of the marine core was developed by using the magnetic inclination of the secular variation record and two ^{14}C dates carried out on benthic and planktic foraminifera at depths of 527 and 599 cm. Its pollen record shows a gradual irreversible trend towards increasing aridity since 5700 cal. B.P. and, just after around 5100 cal. B.P., a *Picea* decline and a *Quercus ilex* type increase indicate less cool conditions. Human impact introduces rapid changes, such as the decrease of *Abies alba*, thinned by the reduction of precipitation and further cleared before or during the Early Bronze Age, followed by the fall of oaks. The latter started after around 3900 cal. B.P., and became evident at around 3600 cal. B.P. The gradual increase in signs of open landscape and woodland clearance correspond to the onset of Middle Bronze Age settlements in the Po valley, and to the development of the cultural landscape in the region. The impact of the *terramare* people includes woodland management by coppicing, and division of the territory into a patchwork of pastures and fields. Dry environments are indicated mainly by Cichorioideae, resulting from the continued human pressure, and these spread since the Recent Bronze Age. Of the possible causes for the decline of the *terramare*, we suggest that climate would have been less important in the decline than in the onset phases. The later cultural landscapes are mainly indicated by the trends of the *Olea*, *Juglans* and *Castanea* (OJC) records, besides those of cereals. At around 700 cal. B.P., the "chestnut landscape" spread while modern times are shown by the finds of *Zea mays*.

Keywords Bronze Age · Environmental changes · Human impact · Marine core · Mediterranean basin · *Castanea*

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Introduction

The beginning and evolution of cultural landscapes are indicated at least from the mid-Holocene onwards in the Mediterranean basin (Mercuri et al. 2004; Roberts et al. 2011; Sadori et al. 2007). Most of the biological archives,

including pollen, upon which past environmental reconstructions are based respond to both climate change and human impact. Therefore, the significance of biological records in sites where changes occurred frequently and rapidly is ambiguous (deMenocal 2001; Oldfield and Dearing 2003; Roberts et al. 2004; Sadori et al. 2011; Weninger et al. 2009).

Comparison between terrestrial and marine records helps to explore the differences between the human and climatic types of evidence, thus improving understanding of the climate system (Tzedakis et al. 1997). In these researches, archaeological sites are helpful because they provide by definition evidence of human presence, and therefore the association between on-site and off-site pollen records is a key tool for highlighting the human action influencing an area in specific times (Berglund 2003; Mercuri 2008a).

This paper presents a comparison between original pollen data from a mid-late Holocene marine core and from a Middle to Recent Bronze Age archaeological site, both with evidence of climate changes and human impact (Fig. 1). The focus is on the cultural landscape in Italy, and in particular on the landscape that developed there since the Bronze Age, a key time of land transformation in the peninsula. The cultural landscape, as any landscape, has its roots in a natural environment, and the relation between natural and human landscapes must be investigated to understand to what extent environmental changes depend on different biological variables (Mercuri et al. 2010a). Therefore, the records preceding the Bronze Age phase must be briefly examined. Then, the main steps of cultural landscape development will be discussed.

The marine core RF93-30 comes from the western flank of the central Adriatic Sea, and its sediment source area includes the Po valley and the eastern flanks of the central and northern Apennines (Trincardi et al. 1996). The archaeological site is the Terramara di Montale, located in the central-southern part of the Po plain, in Emilia Romagna, and it collected pollen from the surroundings of the settlement, and partly from the higher mountain vegetation belts. It represents one of the most impressive high-resolution on-site pollen sequences of this area, where suitable archives are not available in the vicinity of most sites. For example, a pollen profile sampled in a palaeo-channel approximately 150 m to the southwest, far from the centre of the Terramara di Montale, only showed a ten centimetre layer of Bronze Age deposits (Mercuri et al. 2006a).

Multiproxy data reports on the two records have already been published elsewhere (from core RF93-30: Lowe et al. 1996; Oldfield et al. 2003; Piva et al. 2008; from Terramara di Montale: Cardarelli 2009a; Mercuri et al. 2006b). In this paper, the data have been recalculated to reconstruct the vegetation history as well as the development of the

Fig. 1 Location map of sites quoted in the text. *1* marine core RF93-30 (42°40′N 15°40′E); terrestrial sites: *2* Terramara di Montale (44°30′N 10°55′E); *3* Domagnano (44°30′N 10°55′E); *4* Monte Castellaccio (44°09′N 11°31′E); *5* Lago Battaglia (41°54′N 16°08′E); *6* Lago Alimini Piccolo (40°11′N 18°26′E); *7* Lago di Mezzano (42°36′N 11°46′E); *8* Lago di Pergusa (37°30′N 14°18′E); *9* Lago di Nemi (41°42′N 12°42′E); *10* Terramara di Santa Rosa (44°50′N 10°32′E); *11* Necropoli di Casinalbo (44°36′N 10°50′E); *12* Lago di Albano (41°45′N 12°40′E); *13* Lago di Vico (42°19′N 12°10′E); *14* Villaga-Barbarano (45°23′N 11°33′E); *15* Pavullo nel Frignano (44°19′N 10°50′E); sites quoted for modern pollen rain: *16* Onfiano (44°29′N 10°33′E); Vignola (44°29′N 11°20′E)

agricultural/cultural landscape in the relevant source areas during the mid-Holocene.

A key phase of climatic changes around the 5th–4th millennium B.P. was fairly synchronous with profound changes in environmental and cultural systems which caused an increase in social complexity in the Mediterranean basin (Berger and Guillane 2009; Brooks 2006; Mercuri et al. 2011). This paper aims to contribute to the debate on the forces involved in these changes. How much did vegetation changes depend upon climatic changes, and how much were they also determined by human activity? How synchronous was the response of vegetation to changed forces? The climate imprint is followed mainly through the records of selected uncultivated trees while the evolution of the cultural landscape over time, as an adaptive response to climate change or to local environmental variables, is reconstructed through the trends in the records of presently cultivated trees.

Materials and methods

The two records reported here were studied for pollen within independent multidisciplinary co-operations and European projects.

The marine core RF93-30

Core RF93-30 (Lat. 42°40′01″N; Long. 15°40′03″E) was collected 18 km north of the northern coast of the Gargano promontory and 55 km southeast of the centre of the Mid-Adriatic Depression (MAD). It was taken in a water depth of 77 m by the CNR–IGM teams from Bologna, and was approximately 627 cm long. The stratigraphic context is given in Trincardi et al. (1996). The core was studied in the EU-funded PALICLAS project (Guilizzoni and Oldfield 1996) and the results, including pollen analysis, indicate that the sediments represent a plume of terrigenous material from the land which was mostly deposited within the HST (High-Stand Systems Tract—last 5.5 ka), with a strong link between land cover, surface processes and near shore marine sedimentation (Oldfield et al. 2003). The published data show a significant correlation between the non-arboreal pollen percentages and a mineral magnetic parameter (% Hard IRM) that was interpreted as being representative of the human impact signal.

Palaeomagnetic data, correlations with other marine cores and paleomagnetic dates were useful to assess the age-depth model reported in Oldfield et al. (2003). The original chronology of the core was developed by using the secular variation record and two ^{14}C dates carried out on benthic and planktic foraminifera at 527 and 599 cm. We have reconsidered the original data to develop a new age-depth model that is slightly different to the previous one. The ^{14}C dates were recalibrated with the Calib 6.0 program which uses the 2009 international calibration dataset (Stuiver and Reimer 1993). The secular variation record reported in Fig. 2 was compared by Oldfield et al. (2003) with the magnetic inclination record of the historically dated Etna lavas studied by Rolph and Shaw (1986), and the UK master curve published by Turner and Thompson (1981). However new recent palaeomagnetic data from marine sediments (Rolph et al. 2004; Vigliotti 2006) and the Etna lavas (Speranza et al. 2006) show that both records have inadequate chronologies, and for this reason only the most prominent and well dated features of the magnetic inclination were used for the new age-depth model. Five features recognized in the inclination record were correlated with features α, β, γ, δ, and ε (Fig. 2). The choice of these features is also based on chronological constraints. The youngest four occurred during historical times and their ages are strongly supported by archaeomagnetic results. The last feature (ε) exhibited a consistent age (3525 years
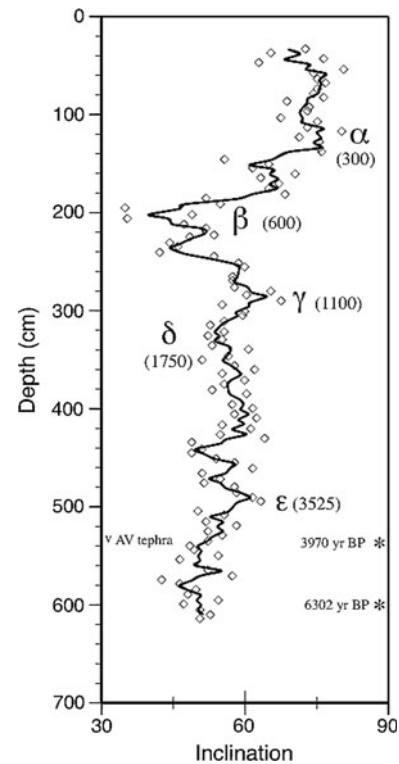

Fig. 2 Magnetic inclination record for Core RF93-30 with the features (α, β, γ, δ, ε) used for the age-depth model. *Solid line* represents the smoothed record (3 points) of the subsamples (*open symbol*); *calibrated ^{14}C date

B.P.) in other cores from the Adriatic (Vigliotti 2006) and it is also constrained by the presence of the Avellino tephra just 34 cm below. The age of the sediments at 527 cm (3970 ± 147 years cal. B.P.) is well in agreement with the presence of this tephra at 529 cm, as also indicated by geochemical data (Sulpizio et al. 2010). The Avellino tephra has a high stratigraphic value for the Bronze Age (Sulpizio et al. 2008; Zanchetta et al. 2011) and has recently been precisely dated at 3945 ± 10 years cal. B.P. by Sevink et al. (2011). This age is within the margin of error of our dating with a slight difference of about 100 years that can be easily explained by the older ages usually obtained by benthic foraminifera as well as by differences in the reservoir of the Adriatic basin (Langone et al. 1996).

Two peaks in the magnetic concentration were identified at 116 and 294 cm and even if volcanic ash was not recovered in the sediments, the peaks could be representative of tephra layers as already suggested by Oldfield et al. (2003). The chronology suggests a possible correlation with the A.D. 781 and 1631 events even if dispersion axes and finds in cores collected in the same area (Sulpizio et al. 2010) could indicate a stronger correlation with the Pollena eruption (A.D. 472) for the latter.

A total of 63 pollen samples were collected at 10 cm intervals, from 4 to 622 cm. Based on the age-depth scale,

the layers between around 534 and 436 cm were deposited during the Bronze Age in Italy (4250–2900 cal. B.P., Cardarelli 2009b). The layers between around 502 and 462 cm (about 40 cm spanning the interval around 3622–3180 cal. B.P.) were deposited approximately during the Middle and Recent Bronze Age Terramare Culture period (3600–3120 cal. B.P., Cardarelli 2009b).

The archaeological site of Terramara di Montale

Terramara di Montale (Lat. 44°30′N, Long. 10°55′E; 71 m asl) was established on a natural hillock surrounded by an embankment and ditch. It was one the largest sites of the Terramara Culture which included hundreds of settlements and many thousands of inhabitants on the Po plain from around 3600 to 3120 cal. B.P. (Bernabò Brea et al. 1997). The great socio-economic system of the *terramare* consisted of a complex territorial association of villages, usually one per 9–10 km^2, or less. They were 1–2 ha in area in the earlier phases, and enlarged to up to 20 ha in the Late Bronze Age, from ca. 3300 cal. B.P. Each settlement had a territory which it used for subsistence resources, and a more or less extended area of influence, depending on the settlement and the chronological phase. In the Terramara di Montale, it was approximately 14 km^2 during its peak.

Today, the site is located in the small town of Montale in Modena-Emilia Romagna, just below the hill belt of the Tusco-Emilian Apennines. First discovered at the end of the 19th century, modern research on the site includes archaeological, stratigraphical, archaeozoological and archaeobotanical analyses (Cardarelli 2009a).

The chronology is based on archaeological dates, supported by eight radiocarbon dates (Mercuri et al. 2006b). It is assumed that the *terramara* was inhabited for 350 years, from about 3550 to 3200 cal. B.P.

A record of 43 pollen samples from the on-site profile P1, 350 cm deep, was collected from inside the village. It spans from before the Bronze Age to the modern age, but samples from layers deposited after the abandonment of the *terramara* were sterile.

Pollen preparation and diagrams

Pollen samples were prepared following van der Kaars et al. (2001) (see also Florenzano et al. 2012). *Lycopodium* tablets were added for calculation of concentrations. Residues in glycerol were mounted in permanent slides. Identification was made at 1,000× magnification. Cerealia pollen was identified using Andersen (1979), Beug (1964) and Fægri and Iversen (1989). *Zea mays* was distinguished on the basis of reference slides and literature (ESM Table 1). The term Chenopodiaceae (*nom. cons.*, APW: www.mobot.org/mobot/research/apweb/), used in many

Fig. 3 Core RF93-30, pollen diagram, depth scale. **a** percentages of ► selected taxa; **b** percentages of wet environment taxa, and sums. Percentages are calculated from a pollen sum that excludes *Pinus*, Cichorioideae and cereals. The percentages of these three latter taxa and of other sporomorphs (fern spores, reworked pollen) are calculated from different sums, each of them including the pollen sum plus these various taxa. Total concentration refers to the total amount of pollen grains per cm^3 (pollen sum + *Pinus*, Cichorioideae and cereals); exaggeration × 10

reference pollen records, was preferred to Amaranthaceae, and Cheno/Amaranthaceae. Pollen nomenclature mainly follows Moore et al. (1991).

In core RF93-30, a mean of about 520 pollen grains per sample were counted. Pollen Zone III and Sub-zones c, d and e were labelled using the same terms used within the PALICLAS Project for the Adriatic Core PAL94-8, which spans approximately the last 18,000 years (Guilizzoni and Oldfield 1996). As the mid and late Holocene are more expanded in RF93-30 than in PAL94-8, a new zonation was used in this paper, based on visual examination and CONISS (Constrained Incremental Sum of Squares; Tilia program; Grimm 2004).

In the Terramara di Montale, a mean of about 970 pollen grains per sample were counted. The zonation in this paper is the same as in Mercuri et al. (2006b).

The published percentage pollen diagrams were calculated from pollen sums that excluded overrepresented pollen grains, but these were different in the two deposits. Therefore, in this paper, percentages were newly calculated from a pollen sum that excludes *Pinus* (previously excluded from RF93-30), and Cichorioideae and cereals (previously excluded from the *terramara*). The pollen diagrams were drawn with TGView (Grimm 2004).

Results

The marine core RF 93–30 (Figs. 3, 4)

The main features of the pollen zones are described below, and further details are given in ESM Table 2. The pollen percentages and concentrations presented below are mean values for the relevant sub-zones.

Sub-zone IIIc (622–485 cm; around 7046–3360 cal. B.P.). There are high mean pollen concentrations (ca. 31,600 p/cm^3), corresponding to the lowest sedimentation rate; deciduous mixed oak woodland has the maximum value of 51% and would have been the main woody vegetation with *Quercus* (43%), *Carpinus orientalis/Ostrya carpinifolia* (3%), *C. betulus* (2%), *Corylus*, *Ulmus* and *Alnus* (1% each), *Acer campestre* type (0.8%), *Fraxinus* (0.7%). Conifers were fairly spread with *Pinus* (23%), high values of *Abies* (4%), and significant values of *Picea* (1%)

and *Juniperus* type (1.3%). *Quercus ilex* type (8%) is significant while other Mediterranean trees are negligible (0.4%). *Fagus*, fairly steady around 7%, has its highest values (max. 10% at 582 cm—around 5750 cal. B.P.). *Betula* is low but common (0.5%). *Castanea*, *Juglans* and *Olea* are present only sporadically (<0.1% each). Within this phase, just after around 5100 cal. B.P. (IIIc2), the *Betula* and *Picea* decline is fairly synchronous with the increase of the Mediterranean taxa *Pistacia* and *Quercus ilex* type. This marks a change towards relatively less cool conditions.

In the sub-zone, Poaceae-wild grass group (6%) and Cyperaceae (7%) are low. Among cereals (0.2%), *Hordeum* type is low, and *Avena/Triticum* type is only found in one sample (572 cm, around 5430 cal. B.P.). There are high values of reworked pollen (41%).

At around 3900 cal. B.P. (522 cm), deciduous oaks and other broadleaved trees reach maximum values. Then gradually increasing landscape openness coincides with a dramatic fall of oaks at around 3600 cal. B.P. (IIIc3). This loss of woodland corresponds to the beginning of Middle Bronze Age settlements in the Po valley.

Sub-zone IIId (484–133 cm; around 3350–350 cal. B.P.). Concentration (ca. 10,000 p/cm3) and *Pinus* percentages (15%) decrease towards the top. Tree percentages (58%) show a significant reduction, subsequent recovery and second reduction. For example, the mixed oak wood taxa notably decrease to 42%, although *Ulmus* (0.6%) decreases gradually. Subsequent woodland reduction and regrowth match the fairly gradual opening of the landscape in response to both drier and possibly warmer climatic conditions and the increase of human pressure. The first, climatic, factor is detectable, for example, in the decline of *Abies* (2%), which decreases fairly gradually, and of *Fagus*, which reduces to about half (3.7%). Also *Picea* and *Betula* are lower than previously (1.1% vs. 1.4%). *Quercus ilex* type (3%) drops, starting a decreasing trend while other Mediterranean plants increase (2%). *Juniperus* type (2%) increases with oscillations.

The second, human, factor, is detectable in the rise of anthropogenic pollen indicators. *Castanea*, *Juglans* and *Olea* pollen become more abundant, also increasing at the top. There is a general increase of Cichorioideae (14%), Poaceae and Cyperaceae (12% each), and less abundantly
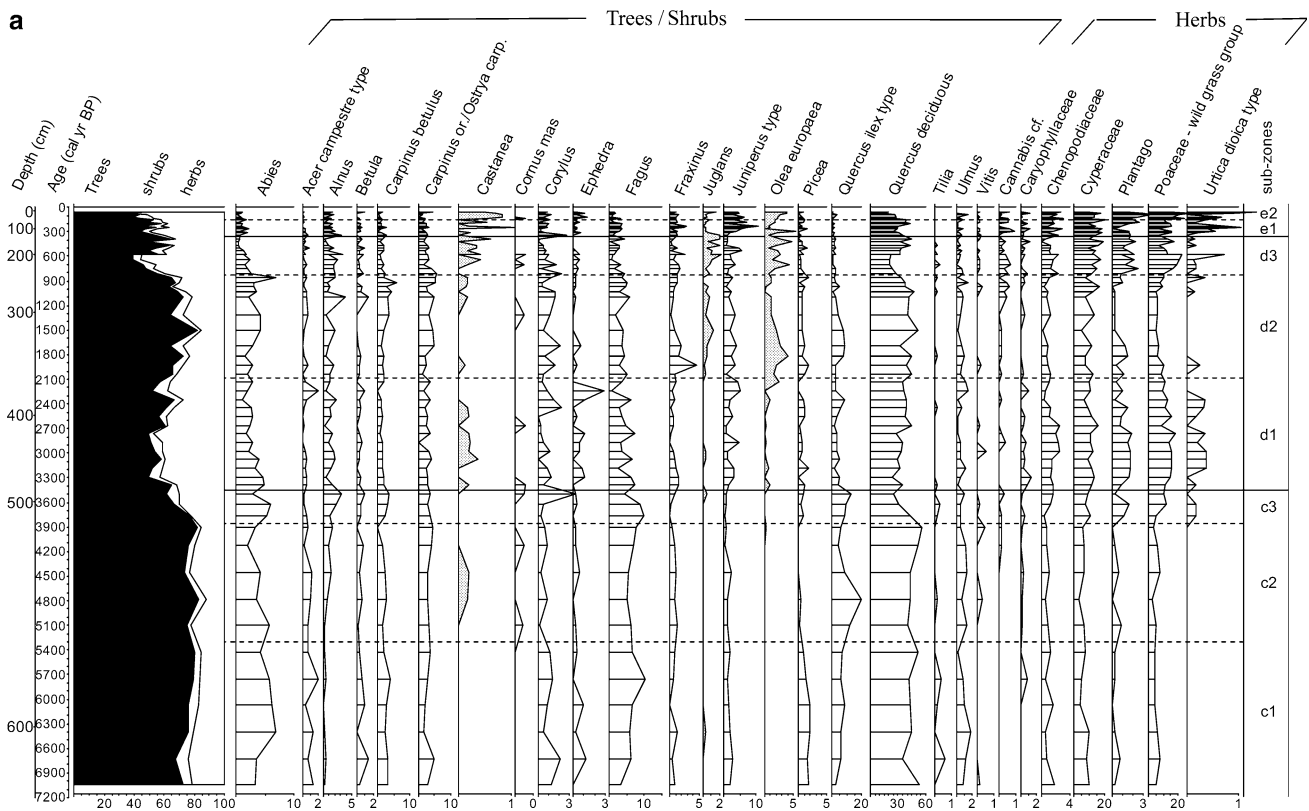

Fig. 4 Core RF93-30, pollen diagram, age scale. **a** percentages of selected taxa; **b** percentages of selected taxa, and sums. Pollen sum excludes *Pinus*, Cichorioideae and cereal pollen. The curve of 'other Mediterranean' includes *Myrtus*, *Pistacia* and *Phillyrea*; 'cultivated trees' includes *Castanea*, *Juglans* and *Olea europaea*; 'anthropogenic indicators' includes *Centaurea nigra* type, *Plantago lanceolata* type, *Urtica dioica* type (black curve), *C. cyanus*, *P. media/major*, *P.* undiff., *Artemisia*, cf. *Cannabis*, *Convolvulus*, *Mercurialis*, *Papaver rhoeas* type, *Polygonum aviculare* type and *Rumex*

of Asteroideae (2%). Cereals and ruderals become continuous.

At around 1100 cal. B.P., the ratio of *Quercus ilex* type to *Juniperus* pollen is reversed in favour of the latter, showing that there was a tendency of the Mediterranean evergreen woodland to degrade to shrubby open environments. From around 775 cal. B.P., and then between 700 and 600 cal. B.P. (IIId3), evident woodland clearance events coincide with the spread of cultivated trees, pasture and cereal fields during wetter climatic phases.

Sub-zone IIIe (132–134 cm; around 348–358 cal. B.P.). The first record of *Zea mays* marks the bottom of this zone. Trees decrease with oscillations (46%); *Picea* and *Betula* are lower (0.7%). The mixed oak wood has a further decrease to 35%: *Acer* (0.2%) becomes sporadic, *Tilia* is absent. *Quercus ilex* type (1%) has a further reduction while other Mediterranean trees increase (3%). *Juniperus* type (5%) increases as well as cereals (2%). *Urtica dioica* type (0.8%) has its highest and continuous curve.

These last three hundred years saw a further reduction of woodland and expansion of dry shrubby and grassland environments under human pressure. A certain amount of tree renewal in recent times is attributable to agricultural practices in the case of chestnut woods and olive groves, and reforestation practices with beech, fir or other trees.

The archaeological site of Terramara di Montale (Fig. 5)

Six pollen zones are distinguished. Zone MTI1 at the bottom was deposited 'before the Terramara', while the other zones from MTI2 to MTI6 describe the different archaeological phases of the settlement (Mercuri et al. 2006b).

The chronology of the archaeological phases is shown in years before present (B.P.) for uniformity. The dates do not cover exactly the time span of each zone, and can overlap because the radiocarbon dates usually have wider age ranges than the actual chronology of the archaeological layers. The pollen percentages are mean values per zone calculated from the pollen sum in this paper and can therefore slightly differ from those previously published.
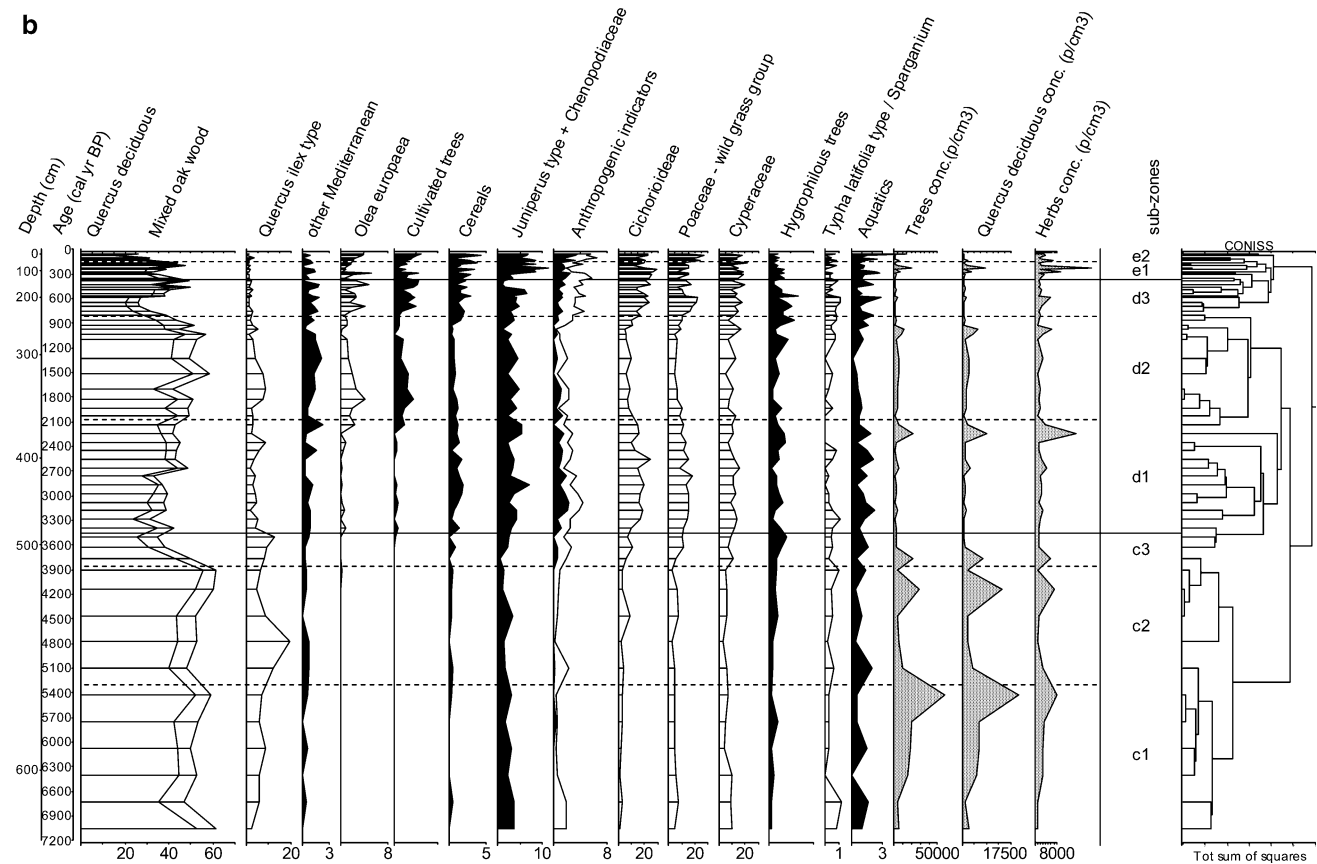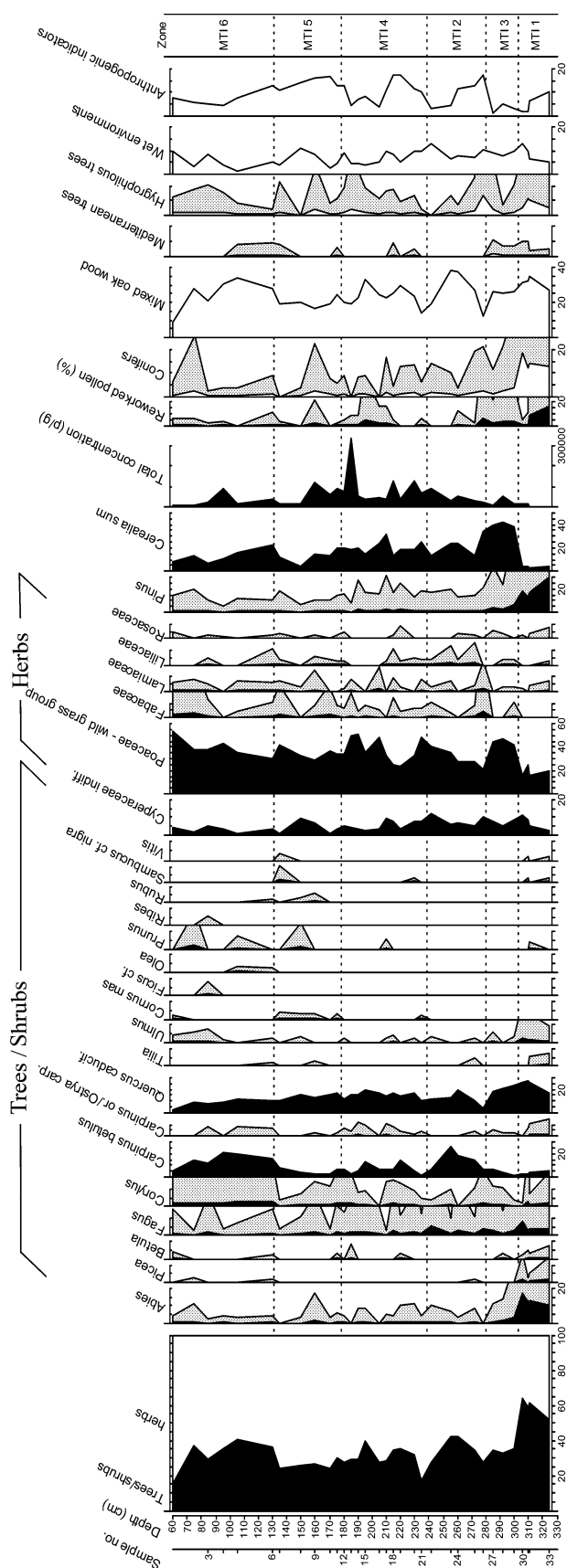
b

Fig. 4 continued

◀**Fig. 5** Terramara di Montale, pollen diagram of P1 record. Percentages of selected taxa and sums. Pollen sum excludes *Pinus*, Cichorioideae and cereal pollen. Anthropogenic indicators include *Centaurea nigra* type, *C. cyanus*, *C.* undiff., *Plantago lanceolata* type, *P. media/major*, *P.* undiff., cf. *Agrostemma*, cf. *Arctium lappa*, *Artemisia*, cf. *Cannabis*, *Convolvulus*, *Mercurialis*, *Papaver rhoeas* type, *Polygonum aviculare* type, *Rumex*, *Urtica dioica* type, *Vicia faba*

MTI1 (325–305 cm; before the *terramara*). The highest mean percentage of trees (59%) but low pollen concentrations (9,500 p/g) are recorded. Conifers (*Abies* 13%, *Picea* 1%, *Pinus* 20%), *Fagus* (5%) and *Betula* (0.5%) reach their maxima. Broadleaved trees include *Quercus* (24%), *Carpinus betulus* (4%), *Ulmus* and *Corylus* (2% each), *Tilia* (0.3%). Hygrophilous taxa include *Alnus* (3.1%, the highest value), *Populus* (0.6%) and *Salix* (0.1%). *Castanea* and *Juglans* are present. Cereals are important (4%), with roughly twice as much *Avena/Triticum* as *Hordeum* group, as in the following zones. Cichorioideae (40%) are abundant.

MTI2 (304–281 cm; 3555–3460 cal. B.P.; archaeological Phase I). Pollen concentration triples (26,000 p/g). Trees are halved (34%), largely due to conifers (2%, and *Pinus* 4%), *Fagus* (3%), *Betula* (0.1%), and *Alnus* (0.4%). Deciduous *Quercus* decreases at the top (21%); *Juglans* is present. Cereals (40%) and wild Poaceae (45%) also increase notably, while Cyperaceae remain steady (7%, as in the previous zone) and Cichorioideae decrease to 36%.

MTI3 (280–239 cm; 3550–3400 cal. B.P.; archaeological Phases I–II). Concentration doubles (47,000 p/g). Trees are steady (mean 35%) but *Carpinus betulus* (14%) notably increases, while *Quercus* (12%) falls by half. *Pinus* sharply drops to 2%. *Fagus* is steady (3%), and *Betula* is absent. *Alnus* decreases (0.1%) while other hygrophilous trees increase. Wild Poaceae decrease to 30%. Cichorioideae double (60%), and cereals are halved (22%).

MTI4 (238–179 cm; at around 3400 cal. B.P.; archaeological Phases II–III). Concentration doubles again to its maximum mean (94,000 p/g). Tree pollen decreases (30%) including *Fagus* (2%), and especially *Carpinus betulus* (7%); *Quercus* recovers to 15%. *Alnus* (0.6%) increases again, but other hygrophilous trees do not. *Castanea* is present again, with *Juglans*. Cereals are steady (21%), and wild Poaceae (38%) increase alternating with Asteroideae (5%) and Cichorioideae (63%). Cyperaceae begin to decrease (6%).

MTI5 (178–131 cm; 3440–3270 cal. B.P., for phases V-VI; archaeological Phases III–VII). Trees continue to decrease (26%), including *Quercus* (14%) and *Carpinus betulus* (5%). Cereals drop to 13%, and Cichorioideae continue to increase (70%). There are traces of *Castanea* and *Cornus mas*.

MTI6 (130–160 cm; 3390–3270 cal. B.P.; archaeological phases VIII–X). Trees, especially *Carpinus betulus* (15%), increase again to 32%, while *Quercus* notably decreases (8%). Cereals are steady on average (13%) showing a decreasing trend, and Cichorioideae decrease (51%).

Discussion

The pollen source areas of the two records are very different. Mainly the Po valley, and also the regions from north to south Italy, may be represented in core RF93-30, but the Po plain area of influence of the *terramara* is prevalent in the archaeological record. In this sense, pollen from the *terramara* gives mostly local information about a limited area surely influenced by human action, while the marine core data shows regional vegetation changes occurring as the result of climate and human influences over a wide area.

The pollen zones of core RF93-30 match the main vegetation changes in terrestrial environments for the last 7,000 years, and give increasing details from about 4460 cal. B.P. onwards, thanks to sedimentation rate amplification (Fig. 4). To understand the origin of the main changes synchronous with the Bronze Age and following periods, some notes on the floristic assessment and vegetational events occurring previously must be discussed.

Pollen source area and woodland composition of core RF93-30 compared with other pollen records

The woodland composition of the mid-Holocene diagram is marked by mesophilous rather than by Mediterranean plants (Figs. 3, 4b). Considering the geographical position of the marine core, close to the central Italian coast, the representation of Mediterranean plants is rather lower than expected. Pollen assemblages reflect the large pollen source area of this core, covering the Po valley and north-central Apennines (Oldfield et al. 2003), and only in part the central and southern Italian peninsula.

The evidence for prevailing mixed oak wood largely consists of trees known to have been part of the vegetational climax association of the Po plain. Besides some deciduous oaks, there are *Carpinus betulus* and *C. orientalis/Ostrya carpinifolia*, *Acer campestre* type, *Fraxinus*, *Tilia* and *Ulmus*. *Pinus* and some *Abies* were distributed in woodlands in higher vegetational belts. In the Po valley, pine pollen is known to have dominated spectra, especially those from the plain, as a result of long distance transport from the Apennines to the open grasslands which were spreading over plains in the Pre-boreal (Accorsi et al. 2004).

Also, the fairly continuous curve of *Picea* in core RF93-30 is more compatible with spectra from northern than from central and southern Italy (for example, Accorsi et al.

1999; Caroli and Caldara 2007). *Picea* seems to have vanished earlier from the western than from the eastern side of the northern Apennines, where its pollen was still present in traces until the Boreal, as spruce was being disadvantaged by the increasing temperatures and competition with *Abies*. Spruce lived at higher altitude and it was locally present in southern Italy during the last glacial period (Follieri et al. 1998). Its present day distribution in Italy is limited to the Alps and a few relict habitats in the northern Apennines (Magri and Sadori 1999).

The moisture-requiring *Abies* expanded earlier on the northwestern than on the eastern, drier, side of the northern Apennines (Ravazzi et al. 2006). Although the pace of *Abies* expansion increased during the Holocene in the Alps (van der Knaap et al. 2005), a rapid and sharp decline was evident in the mid-Holocene in the southern Alps and in the northwestern Italian coastal plains. In these regions, increasing human pressure since the Neolithic was among the causes for the decline and local extinctions of silver fir (Bellini et al. 2009; Wick and Möhl 2006). In the Po valley, however, *Abies* notably spread from the Boreal to Subboreal, probably growing in habitats in the plain and as monospecific woods in the hills until at ca. 6000–5500 cal. B.P. (Accorsi et al. 1999; Vescovi et al. 2010). Afterwards, it remained largely confined to the mountains, leaving space for *Fagus* expansion (Accorsi et al. 1996, p. 247).

Based on this, a chronology can be tentatively proposed for the bottom zone of the Terramara di Montale record (MTI1, Fig. 5). The low pollen concentration and large amount of reworked pollen imply an input of alluvial deposits carrying down pollen from higher altitude vegetation belts: (i) maxima of *Abies*, *Fagus*, *Betula*, *Picea* and *Pinus* suggest wet and cool climate conditions; (ii) cereal pollen testifies that arable fields were already present. Combining the evidence, these bottom sediments may have been deposited during an early mid-Holocene wet and cool phase at least of Neolithic age or later, therefore falling between 7500 and 5500 cal. B.P. Similar layers were found just below other archaeological deposits in this area, for example under the Roman deposit at Domagnano, San Marino (Mercuri et al. 2009) and under the Bronze Age layers at Monte Castellaccio, Emilia Romagna, (Mercuri et al. 1999). In southern Italy, a nearly continuous presence of *Abies* was recorded in Apulia until 4875 cal. B.P., and subsequently its occurrence became sporadic (Di Rita et al. 2011).

Fagus is currently part of the woodland of the northern and central Apennine mountain belts where *F. sylvatica*, also associated with *Abies alba*, grows above 800 m, extending up to 1,800 m. It is also part of the beech communities of the low mountain belt in southern Italy, the Doronico-Fagenion (Di Pietro et al. 2004). From the Lateglacial onwards, beech expanded exponentially from its

glacial refugia until about 3500 cal. B.P., and then began to expand at a slower rate than previously (van der Knaap et al. 2005). Cooling and wetter conditions favoured beech growth, but human activity and competition with other trees may also have influenced the changes of its rate of spread (Magri 2007; Valsecchi et al. 2008). According to Magri et al. (2006), the rapid expansion of *Fagus* had occurred since the early Holocene in southern and central Italy, and in the 6800–5700 cal. B.P. phase along the inner Alpine chain and in the northern Apennines. In core RF93-30, an earlier decrease of *Fagus* occurred just after around 5700 cal. B.P. (582 cm) and, in the general indication given by these spectra, it suggests that a trend towards increasing dryness started around this date.

The progressive aridification from c. 6500 to c. 5000 cal. B.P.

The progressive aridification of climate during the mid-Holocene is evident at many Mediterranean sites (Sadori et al. 2005; Pérez-Obiol and Sadori 2007; Roberts et al. 2011). Since around 6000 cal. B.P., besides the decline of *Abies* in northern Italy, there was a lowering of lake levels in central Italy (Giraudi 2004; Giraudi et al. 2011) and in the southern basin of the Dead Sea (Roberts et al. 2001), and a progressive spread of xerophilous vegetation in Saharan regions (Kröpelin et al. 2008; Mercuri 2008b; Cremaschi and Zerboni 2009). At around 6000–5400 cal. B.P., a climate-driven decline of woodland and mesophytic trees began in the western Mediterranean region (Carrión et al. 2001; Fletcher and Sánchez Goñi 2008).

On the northeastern coast of Gargano, close to the location of core RF93-30 (Fig. 1), the mid-late Holocene sequence of the dried-out Lago Battaglia shows that the coast was characterised by Mediterranean sclerophyllous vegetation composed of *Quercus ilex*, *Olea*, *Phillyrea* and *Pistacia*, and halophyte-xerophyte associations including Chenopodiaceae and Caryophyllaceae; a higher belt was covered by a mixed oak wood with *Ostrya carpinifolia*, *Carpinus orientalis* and *Corylus*; moreover, *Fagus*, *Taxus* and deciduous *Quercus* grew at the highest elevations (Caroli and Caldara 2007).

The further increase of dryness from 5500 cal. B.P. onwards, although a complex event with wet and dry oscillations (Magny et al. 2009a), led through increasing aridification to conditions similar to today's in many Mediterranean sites (Jalut et al. 2000).

In RF93-30, *Picea* significantly decreased at around 5100 cal. B.P., and then a dry or possibly warm climate signal is suggested by the peak of *Quercus ilex* type which is synchronous with the minimum of *Fagus* at around 4780 cal. B.P. Between 5200 and 4300 cal. B.P., a dense evergreen oak woodland dominated the landscape around Lago Alimini

Piccolo (Salento, southern Italy), only interrupted by a temporary drop at 4800–4500 cal. B.P. probably due to the beginning of cultivation (Di Rita and Magri 2009).

From the tree decline at c. 4300–4200 cal. B.P. to the deforestation at c. 3600 cal. B.P. (Fig. 6)

In central Italy, woodland opening is shown by the decrease of tree pollen concentration at Lago di Mezzano (Sadori and Giardini 2008), as well as at Lago dell'Accesa and Lago di Vico, at around 4300 cal. B.P. This evidence significantly matches data from Lago Albano and Lago di Nemi where palaeomagnetic correlations date an increase in sediment delivery, that is an index of loss of woodland (Rolph et al. 2004), at the core sites at around the same date. At around 4200 cal. B.P., evergreen oaks and then *Juniperus* expanded together with drought resistant vegetation in southern Spain (Carrión et al. 2003). Events were different in Italy, with a tree decline mainly affecting evergreen vegetation associated with the change from shrubby woodland to open landscape, showing a time-transgressive trend from southwest to central and then to southeast Italy, mainly ascribable to reduction of precipitation (Di Rita and Magri 2009).

The fall of *Quercus ilex* type occurred in core RF93-30 at around 4130 cal. B.P., and it is contemporary with both the rise of deciduous oaks and the thinning of *Abies* and *Juniperus* type.

Also at Lago Battaglia, evergreen *Quercus* had a sharp fall at around 4200 cal. B.P., and woodland loss together with a change in fire frequencies was irreversible. Caroli and Caldara (2007) observed that the dramatic fall of tree concentration was not associated with an increase of anthropogenic indicators. With a different interpretation, however, the rise of Cichorioideae and *Plantago* percentages (p. 320) may be regarded as a sign of increasing pastoral practices and settlements in the terrestrial source area (Mercuri et al. 2010b).

In core RF93-30, the noticeable decrease of *Abies* may be a result of silver fir felling that may have preceded that of oaks in an earlier Bronze Age phase. The decline of the broadleaved trees *Carpinus betulus*, *Fraxinus* and *Ulmus* occurred about a century later (Figs. 4a, 6). These particular trends suggest that: (i) human action may have produced these effects, because trees were used for building, fire and fodder (Mercuri et al. 2006b; Montecchi et al. in press); (ii) human effects on vegetation were delayed by some years after climate changes became established.

Fig. 6 Selected taxa and sums of the two records. Top, Terramara di ▶ Montale, pollen diagram of P1 record; bottom, Core RF93-30 showing the two thousand years including the Bronze Age cultural phase (4250–2900 cal. B.P.). Dotted lines mark the Terramara di Montale phase

Accordingly, Sadori et al. (2004) observed that at Lago di Mezzano, the aridity crisis caused woodland loss, lowering of water level and a decrease of lake size after the Avellino tephra, at around 3800 cal. B.P. Together with the woodland decrease mentioned above, this could be caused by part of the complex climatic oscillation around 4300–3800 cal. B.P. that may have affected the whole central and western Mediterranean area (Magny et al. 2009b). Then, a strong human impact with woodland clearance and spread of anthropogenic indicators was unquestionable at around 3600 cal. B.P. (Sadori and Giardini 2008).

At Lago di Pergusa, Lago di Nemi and Lago Alimini Piccolo, *Olea* spread since 3600 cal. B.P., and this can be regarded as a result of its cultivation at a time of drier climate and of intense fires (Sadori and Narcisi 2001, p. 669; Sadori and Giardini 2007; Sadori et al. 2008). This might also be the cause of the earlier records found in RF93-30 (Sub-zone IIId1; ESM Table 1). At the same time, it is supported at Lago Battaglia where the Mediterranean woodland degraded to shrub formations, visible in the curves of Chenopodiaceae and *Juniperus* type.

In RF93-30, loss of trees would have reduced catchment stability on the land, leading to an increased sediment supply. Evidence of woodland loss was observed in the core by a striking correlation between the pollen record and the magnetic parameters. In particular, the arboreal pollen percentages vary in parallel with the anysteretic remanence (ARM), whereas the herb percentages are in agreement with the antiferromagnetic component (Hard IRM%) (Fig. 7). According to Oldfield et al. (2003), the latter provides evidence of land erosion due to human activity and it seems synchronous with the deposition of the Avellino tephra which also marks an increase in sediment

flux. Then, the most significant changes observed in the RF93-30 core are between 2800 and 1800 cal. B.P., when the temperature apparently increased rapidly over 300 years from 13.8 to 19.6°C, before cooling again by 1800 cal. B.P. (Oldfield et al. 2003, p. 338).

The beginning of the *terramara* and land exploitation since c. 3550 cal. B.P.

In the major sediment source area of core RF93-30, after the cool and wet mid-Holocene phase (MTI1), the establishment of the Terramara di Montale was marked by a dramatic fall of trees (MTI2). The woody cover was thin even before the beginning of the *terramara*, suggesting that people settled in the Po valley looking for suitable areas with natural resources, but which were not too difficult to open up to establish houses and fields.

A significant woodland clearance event has been already observed at the northeastern fringes of the Po plain in the Early Bronze Age as at Canàr (Accorsi et al. 1998) and Lago Lucone (Valsecchi et al. 2006). Settlement continuity and demographic increase characterised the last Early and the early Middle Bronze ages, which are considered to be the times of impressive migration of *terramara* people into the Po plain (Cardarelli 2009b). Woodland clearance became a common feature, resulting in even thinner woods, during the Middle Bronze Age at sites on the central-southern plain. Among these sites, there are Monte Castellaccio, Tabina di Magreta, Palafitta di Parma, and the *terramare* of Santa Rosa di Poviglio (29 m asl) and Baggiovara (59 m asl) (Cremaschi et al. 2006; Mercuri et al. 1999, and unpublished data; Ravazzi et al. 2004). The votive pond of Noceto (76 m asl), filled by a laminated succession indicating a period of

Fig. 7 Rock magnetic parameters %Hard IRM (Isothermal Remanent Magnetization) and anhysteretic remanence (Karm), pollen percentages and sedimentation rate for core RF93-30. The *solid line* represents the accumulation rate between the dated points. A *dotted line* shows the age depth curve
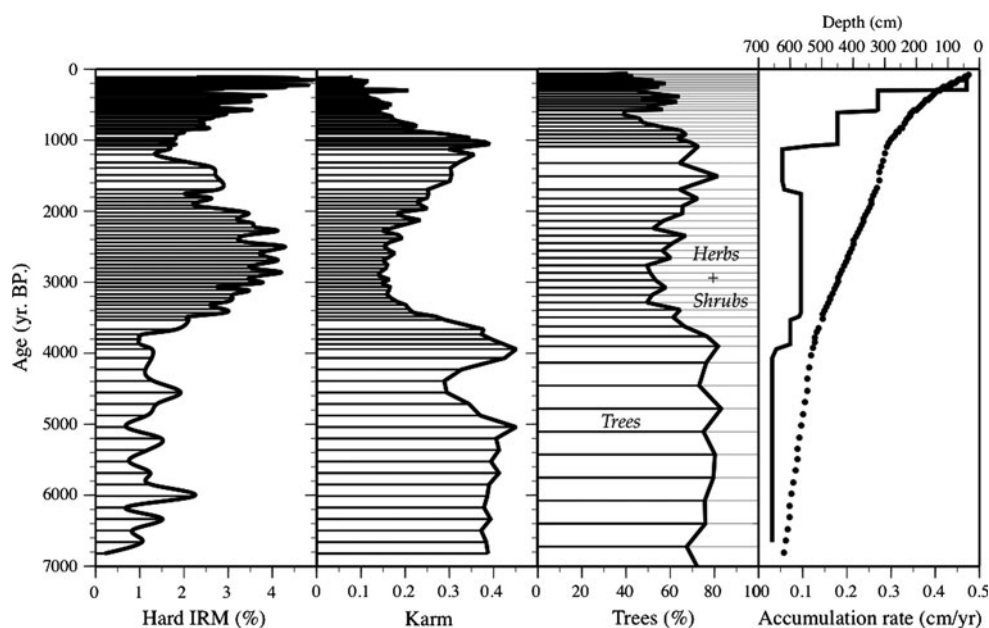
continuous lacustrine sedimentation, was used in the late Middle Bronze Age, and gives evidence that thin tree cover characterised even the low hills (average trees, 15%). Pollen influx of *Abies* and *Fagus* also suggests that some specimens of silver fir and beech probably grew on the wettest sides of the hills, not far from this site (Aceti et al. 2009).

At Montale, woodland clearance first included the significant thinning of *Abies* and other conifers, the gradual decrease of deciduous *Quercus*, the reduced presence of *Carpinus betulus* with *Fraxinus* and *Corylus*, and the reduction of *Betula*, *Fagus*, *Carpinus orientalis/Ostrya carpinifolia* and *Ulmus*. Hundreds of post holes from house piles and a charred trunk of oak on the bottom floor of the settlement suggest that the thinning of oak woods was determined by their use as building material (Cardarelli 2009a). The burning of plants at this stage may have prevented the recovery of some fire-sensitive trees, such as *Tilia* and *Ulmus*. Charcoal and wood data has confirmed great use of oak wood, together with that of hornbeam, beech, maple and alder as firewood and for house construction. Trees were also removed to make space for arable land as testified by abundant cereal pollen and macroremains (Mercuri et al. 2006a).

Wood exploitation created a new equilibrium in the oak woods in which *Carpinus betulus* and *Fraxinus*, together with *Corylus*, gradually spread and occupied spaces left by oaks. Significantly, the fall of oaks at around 3500 cal. B.P. (278 cm) was simultaneous with some spreading of ash and hazel trees, but it was especially hornbeam that gradually expanded when oaks decreased. The following phase (MTI3) saw the re-growth of some trees, so after the intense use for house construction of the first phase, oaks and hornbeams were left to grow. Coppicing of woods was evident at around 3400 cal. B.P. (MTI4) showing peaks of *Carpinus betulus* alternating with those of deciduous *Quercus*, or *Corylus*, or *Fraxinus* and *Carpinus orientalis/Ostrya carpinifolia*. This woodland management introduces a new perspective in the concept of 'terramara woodland clearance'. The *terramara* area appeared as a 'wide artificial clearing' (Cremaschi et al. 2006, p. 90) compared with the surrounding regions of northern and peninsular Italy, but the cultural knowledge of woods seems to have had an important, probably central, role in the subsistence strategy of this culture. Woods were left at the margins of the area of influence of each *terramara*, probably sometimes marking the less intensively used border lands between close settlements.

Woods also provided the fruits of *Cornus mas*, which are characteristic in the seed and fruit record, and its pollen was also found in Bronze Age layers of RF93-30 (Fig. 6). Its fruit stones are common in Bronze Age sites (Bandini Mazzanti et al. 2005; Bellini et al. 2008; Mercuri 2009; Valamoti 2009) and therefore cornelian cherry is an example of a fruit which was collected in the wild. This human behaviour may have rapidly and involuntarily transformed gathering into a protection of selected plants and, as humans acted as agents of zoochorous dissemination and seeds were carried nearer to the sites, they may have contributed to the increase of specimens growing in the area of influence of the site.

The use and management of woodlands would have continued in the surroundings at some distance from the *terramara*, to provide timber and firewood as at the Necropoli di Casinalbo (Montecchi et al. in press).

Pastures would have expanded following the reduction of woods. Their trend can be understood mainly looking at Cichorioideae, which were present in large amounts and gradually increasing towards the top of the diagram. It was suggested that the resistant fenestrate exine of Cichorioideae pollen could be responsible for its overrepresentation in badly preserved material. Although badly preserved Cichorioideae are more easily recognisable than other pollen, they were counted in large amounts in different sediments and contexts. In our contexts, their numbers were not higher in samples with lower pollen concentrations, and the biodiversity of taxa is high, thus permitting us to exclude the possibility that high Cichorioidae results from differential preservation of pollen. Indeed, these plants are known to be so overrepresented in pollen rain from pasture that they are included in the Local Pastoral Pollen Indicators (Behre 1981; Mazier 2007). Sometimes, as in these studies, their percentage trends closely follow those of Poaceae as, for example, in the diagram in Ravazzi et al. (2006, p. 362). Cichorioideae are therefore characteristic of human-shaped open environments and reflect the expansion of dry environments resulting from continued human impact (Mercuri et al. 2010b).

In the Mediterranean basin the process of aridification continued, also testified by the movement of people, as for example the abandonment of the Mezzano lake shores occurring around 3500–3300 cal. B.P. (Jalut et al. 2009; Sadori et al. 2004). At Lago di Pergusa, evergreen trees became dominant from around 3500 to 2500 cal. B.P. (Sadori and Narcisi 2001).

Land use and the development of the cultural landscape

The landscape around the Terramara di Montale evolved in a cultural landscape formed by a mosaic of pastures and cereal fields. Demographic and palynological estimations combined with archaeological evidence have established that, on average, there were about 240 ha covered by grassland and shrubby pastures, and 75 ha of fields, while mixed oak woods largely remained at the edge of the area of influence (Mercuri et al. 2006a, p. 263).

The pollen record ends 70–100 years before the abandonment of the site at 3200 cal. B.P. The decreasing signs

of both woods and fields accompanied by a rise of wild grasses demonstrate a local crisis (Fig. 6, top). At around 3120 cal. B.P., the *terramara* civilisation vanished. Cremaschi et al. (2006) observed that the water management system discovered at the Terramara di Santa Rosa, consisting of large water wells and interconnecting ditches, suffered a clear drop in the water table. Interestingly, aquatics show a short-term decrease at around this phase in RF93-30 (Fig. 6, bottom).

The Terramara di Montale record strongly suggests that local over-exploitation may have amplified the effects of the water crisis. At the Necropoli di Casinalbo, a *terramara* 12 km from Montale, cereals disappear and a dry environment with Chenopodiaceae and Cichorioideae marks the phase of abandonment, from the 12th to 7th century B.C. (Montecchi et al. in press). Overall, demographic increase and soil depletion were among the factors playing important roles in ecosystem dynamics.

Sadori et al. (2004) found intense land use at Lago di Mezzano, at about 3200 cal. B.P. In other lake cores the signs of loss of woodland are evident at around 3000 cal. B.P. (Mercuri et al. 2002). In RF93-30, land use was marked by the continuing trend of deforestation showing a simultaneous decrease of trees, including *Ulmus* and *Fraxinus* (Fig. 4a), and an increase of wild anthropogenic indicators (Fig. 6). Deciduous and evergreen oaks alternate in small oscillations, pastures also spread favouring shrubby environments. This development of the Mediterranean woodland towards shrubby vegetational formations is visible in the spreading of Chenopodiaceae and *Juniperus* type.

The possibly or surely cultivated trees: from wild to human landscapes

The evidence for the evolution of the cultural landscape from pollen evidence, besides that of cereals, can mainly be traced by the trends of *Olea*, *Juglans* and *Castanea* (OJC group, following a S–N transect in Italy; Mercuri et al. 2004).

In RF93-30, the first records of *Olea* and *Juglans* were dated to the Early Bronze Age from around 3900 cal. B.P., but isolated records of *Castanea* were already present earlier, at around 4780 cal. B.P., and then at around 3000 cal. B.P. In the *terramara* diagram chestnut and walnut pollen associated with cereals were already present in the mid-Holocene phase before the beginning of the settlement (MTI1), while *Olea* was only found in the last phase (MTI6).

At Lago Alimini Piccolo, the *Olea* maximum is at around 3100 cal. B.P., while in central Italy, a simultaneous and clear increase of certain or possible cultivated trees occurred about 200 years later. The agrarian and cultural landscape represented by *Olea*, *Juglans*, *Castanea, Vitis* and cereals is recorded at Lago Albano and Lago di Nemi

at around 2900 cal. B.P., and at Lago di Vico after 2700 cal. B.P. (Magri and Sadori 1999; Mercuri et al. 2002). Even if some problems of dating the different cores could be among the causes of these differing dates, it seems that such cultural practices, involving migrations and exchanges between populations, may have been possible only under favourable climatic conditions.

Until around 2700 cal. B.P., at Lago di Battaglia in northern Apulia there was an open landscape with halophytes (Chenopodiaceae), probably influenced by the sea level and favoured by drier and warmer climate conditions than previously (Caroli and Caldara 2007). Pollen evidence for the subsequent decrease of this vegetation is also present, although less evident, in RF93-30. At around 2100 cal. B.P., signs of human impact including the spread of *Olea* and *Juglans* became even clearer in RF93-30. However, human impact was already evident in the Italian peninsula from still earlier times, as shown by thousands of archaeological sites.

Rise and decline of the 'chestnut landscape'

In RF93-30 the final spread of *Castanea* was dated to around 700 cal. B.P. Similarly, in Emilia Romagna, Vescovi et al. (2010) found *Castanea* at around 6500 and at around 3200 cal. B.P., but a clear anthropogenic rise was found at around 800 cal. B.P. The marine record, therefore, could have actually registered the spread of chestnut trees in the Po valley about 100 years later, when the 'chestnut landscape' was so widespread on land that its pollen fallout became clearly visible in the marine records. Besides the environmental changes towards pastures and arable fields, this is a moment of extensive success of the medieval farming landscapes (Bosi et al. 2009).

How far back in time the roots of this landscape can be traced is strictly dependent on the story of the contacts and relationships among local populations and wild plants. As a common human behaviour in handling useful plants (Stemler 1980), trees growing in the wild were searched for fruits or firewood, and then progressively put under special protection and consideration before eventual cultivation. Therefore, the wild chestnut trees may have been affected from early times by human practices of selective cutting, fruit collection, and also the appreciation of the spiritual value of ancient trees, all processes which are known to have involved many plants in our cultural evolution.

The history of *Castanea* in Italy is still a matter of debate. Late-glacial records were found in Villaga-Barbarano (Paganelli and Miola 1991, and references therein), and a significant increase has been evident since around 6300 cal. B.P. at Lago della Costa in Veneto, northeastern Italy (reaching 1–2%; Kaltenrieder et al. 2010). There is a high likelihood that *Castanea* refugia occurred in

Table 1 Past and present *Castanea* pollen in the pollen rain of Emilia Romagna (northern Italy)

a

	Pre-boreal	Boreal	Atlantic	Sub-boreal	Sub-atlantic	Last 50 years	Total sites	Total sites in the synthesis (2000)	Samples per phase
Plain	1	2	3	11	18	16	37	73	829
Hill *	1	1	2	3	11	20	27	31	156
Mountain	0	3	6	11	27	47	67	52	355
Σ of sites	2	6	11	25	56	83	131	155	1,306
Plain	0.1	0.1	0.2	0.7	0.8	1.6			
Hill *	2.0	1.8	0.5	0.6	11.9	9.2			
Mountain	-	0.1	0.2	1.0	2.9	7.5			
Mean % per phase (AP+NAP)	0.7	0.6	0.3	0.8	5.0	6.0			

b

Year	1998	1999	2000	2001	2002	2003	2004	Mean
Max. daily conc. of *Castanea*	267.2	659.6	455.7	225.7	348	343.5	189.6	355.6
Day of max.	07-July	06-July	23-June	22-June	03-July	20-June	09-July	
% on the daily max. conc.	65.7	71.3	53.4	43.6	80.9	67.7	79.1	66.0
Yearly Σ of *Castanea* conc.	3,665.8	5,441.3	3,948.6	2,935	2,573.3	333.2	999.8	2,842.4
% of *Castanea* on the yearly Σ	10	7.1	7.9	6.5	4.2	0.7	3.2	5.7
Yearly Σ of total pollen conc.	36,633.4	76,340	50,087.6	45,181.4	61,283.4	47,813.4	31,170.3	49,787.1

(a) italicised—mean average per phase of chestnut pollen found in sediment cores, archaeological layers and surface soil samples; the grey cells indicate data referring to three or less sites (data elaborated from Accorsi et al. 2004). *Pavullo nel Frignano is located in the hill belt of Modena, and its data were elaborated from Bertolani et al. (1994; and unpublished data calculated on AP + NAP = 100%; *Castanea* % in Pavullo: Atlantic—0.2%, Sub-boreal 0.4%, Sub-atlantic 2.6%). (b) airborne pollen in the years 1998–2004. *Castanea* concentrations (pollen/m³ of air) from the aerobiological monitoring station of Vignola (125 m asl, in the hill belt of Modena province), run by the Laboratory of Palynology and Palaeobotany. Data are elaborated with AEROBIOLOGIA 2.0 (Mercuri et al. 1997) and GEPO programs, and are archived in the R.I.M.A. (Rete Italiana di Monitoraggio Aerobiologico) database

northeastern regions, including Emilia Romagna, the hills being the most suitable refugium area (Accorsi et al. 2004; Krebs et al. 2004).

At this point, some erroneous interpretations reported in previous papers about the presence of chestnut in Emilia Romagna, where the Terramara di Montale lies, must be corrected. We refer to the presence of *Castanea* at the hill site of Pavullo del Frignano, 675 m asl, where early and mid-Holocene records amount to < 2% (Table 1a). Tree curves reported in the pollen diagram by Bertolani-Marchetti et al. (1994), were calculated on a pollen sum which only included arboreal pollen (see the legend, p. 96), and therefore the supposedly 'high values' indicated by Krebs et al. (2004, p. 154), and reported by Vescovi et al. (2010, p. 36) are due to a miscalculation, and not to other improbable causes.

Long-distance transport of this pollen is well-known, but studies on modern pollen rain show that a relatively small amount of pollen is compatible with the presence of chestnut trees in the area. Chestnut pollen in surface samples from monospecific chestnut woods was found to be up to 90% at Onfiano, Emilia Romagna, 450 m asl (Cervi 2003; Montali et al. 2006). Chestnut woods are common in the hills but, although important in the summer, this pollen rapidly becomes a minor part of the airborne regional rain (Mercuri et al. 2001; Torri et al. 2006, Table 1b). The fall of *Castanea*, estimated from about 90% to 6% in the annual pollen rain, is remarkable also taking into consideration different but comparable pollen traps (Ranta et al. 2008; Spieksma et al. 1994). This suggests that values < 2% are evidence of isolated trees rather than of woods.

Chestnut is common in Holocene pollen spectra from Emilia Romagna and notably increases in the hill belt since the Sub-atlantic. This phase saw the development of various cultures such as Iron Age, Etruscan/Celtic, Roman, medieval and modern, which had very different considerations of the role of nature, and economy. Theophrastus, in his *Historia plantarum* (History of plants, book 3), mentions that the chestnut tree was well known in ancient Greece under the name of *Dios balanos* (Zeus acorn)

(Cattabiani 1998). Historians, such as Xenophon and Strabo, report that the chestnut tree was cultivated mainly for its fruits, that fruits were exported by shipping from the mainland of Greece where several villages had the name of *Kastania*, and that its cultivation was based on maintenance of suitable clones by grafting since Greek and Roman times (Zohary and Hopf 2000).

Based on data by Accorsi et al. (2004), and considering sites with reliable archaeological or radiocarbon data, we calculate that the mean percentage of chestnut pollen per phase is slightly lower in pre-Roman (0.6%) than in Roman samples (1.0%). This could suggest that the Romans improved plant distribution in the Po plain. This test needs to be repeated with new sites and areas to improve our understanding of which types of plant management were undertaken by different cultures.

Past evidence of *Castanea* in pollen diagrams is particularly strong from around 3000 cal. B.P., for example coinciding with the 'Cannabis phase' in the Lago Albano and Lago di Nemi, suggesting that pre-Roman people already cared for chestnuts or developed an agrarian landscape (Mercuri et al. 2002; Sadori et al. 2010). The genetic European pattern of the 'carbon isotope discrimination' (D), a complex physiological trait involved in adaptive processes including acclimation, matches the centre of origin of *Castanea sativa* in the Ponto-Caucasian region of Turkey (Lauteri et al. 1997, 2004). Genetical and physiological adaptedness to drought confers on to *C. sativa* the capability to colonize a wide range of environmental conditions (Lauteri et al. 2009). As the present geographical distribution of genetic diversity seems to have been influenced more by human activities than by natural migration and colonization, the integration of palaeoenvironmental and genetic data will help to reconstruct the history of the spread of these cultivated trees.

Modern times are marked by the finds of *Zea mays*, while the chestnut landscape declines. From around 350 to 60 cal. B.P., a number of exotics such as introduced conifers, *Magnolia* and *Eucalyptus*, were recorded in core RF93-30, and an increase in pollen of ornamental plants added evidence of reforestation practices producing the rise of arboreal pollen in recent times (Accorsi et al. 2004).

Conclusions

The history of the nature-culture relationship under Holocene climate changes is a complex issue, in which the development of cultural landscapes is the most evident effect. The botanical information useful for understanding human-related environmental changes is sealed both in archaeological layers and in sediment cores which, although lacking any material cultural evidence, were formed at times of human activities in the sediment source areas (Birks et al. 1988; Fægri and Iversen 1989; Mercuri et al. 2010a; Sadori 2007).

The on-site and off-site terrestrial and marine integration of pollen data has furnished pieces of evidence for the timing and intensity of climate-human forces that shaped the cultural landscapes in the Italian peninsula during the progressive climate aridification in the mid-Holocene.

Many crucial events are enlightened by the data reported in this paper:

– The reduction in the natural woodland vegetation, both deciduous and evergreen trees, is visible from the mid-Holocene, and mainly in the late Holocene.

– An increasing dryness is discernible in RF93-30 by the decrease of *Fagus* after 5700 cal. B.P., and continuing gradually from at least 4780 cal. B.P. Later, after the aridity phase of 4500–4000 cal. B.P. (Jalut et al. 2009), human impact introduced rapid changes which are especially clear in the two records, with the fall of *Abies alba*, thinned by the decrease of precipitation and further cleared before or in the Early Bronze Age, followed by the fall of oak at around 3600 cal. B.P. This chronological shift may rely on different reasons: (a) human effects on vegetation were delayed by a few hundred years after climate changes established; (b) besides cultural variables, drier climate conditions have favoured the spread of agrarian landscapes; (c) earlier human actions are not clearly and immediately evident in marine cores, such as the first Neolithic impact, while they become more and more visible as they intensify. The clearance of trees during the Bronze Age is more evident than the Neolithic spread of cultivated fields that would have caused fewer changes in the pollen rain.

– By definition, human activities contributed to reduce natural woodland by substituting it either with crops and pastures, or by protected plants and managed woods such as chestnut woods, olive groves, orchards or pine woods, but people could also take advantage of open spaces produced by natural changes. Therefore, humans settled in suitable areas where there were both enough natural resources, especially water and wood, and a setting not too difficult to open up to establish settlements and fields. Humans acted as dispersal agents and seeds of useful plants were even involuntarily carried nearer houses, or spread in their territory. In this way, humans contributed to the increase of specimens of useful plants before cultivation.

– The impact of *terramara* in the Middle Bronze Age includes woodland management by coppicing, and development of the cultural landscape into a patchwork of pastures and fields near the site, while woods were left at the margins of the area of influence.

– Dry environments, represented by Cichorioideae, resulting from the continuous human impact, spread since the Recent Bronze Age, reinforcing the aridification process. They were favoured by the (over)-exploitation of land, and continued to be browsed by domestic animals.

– Land over-exploitation and a water crisis are evident at the time of decline of *terramare*. As the start and decline of a culture are critical but very different phases, the present study led us to propose that, in the multi-causal explanation for the decline of the *terramare*, climate would have had a less important role in the decline than in the beginning phases. The statement is a topic for further investigation but parallels well the statement that in the decline of civilizations the cultural complexity of human societies plays a key role (Diamond 2005).

In the evolution of the cultural landscape, presently cultivated trees played an important part. The interpolation of evidence from the terrestrial record of Montale with that from the marine core of RF93-30 suggests that human impact during the Bronze Age acted on the types and equilibrium of woodlands. The evolution of the modern cultural landscape in the Po plain through thinning and management of oak woods therefore became unquestionably evident at around 3600 cal. B.P. Then, the 'chestnut landscape', which still remains characteristic of the Apennine hill vegetation belts, became widely established around 700 cal. B.P., only declining in modern times.

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